

High Performance Commercial Building Systems

PIER Buildings Energy Efficiency Program Final Program Presentation

October 28, 2003

A CEC-PIER Program Activity
Lawrence Berkeley National Laboratory
Prime Contractor

CEC PIER Program Motivation



- **Commercial Buildings:**
 - ~ 33% of all California electricity consumption
 - ~ 40% Impact on load shape and peak electricity
 - Major impact on public health and productivity
- **‘Slow to Change’ building design & operations practices**
- **Progress has been made but measured savings are still below technical and economic potentials**

Broad HPCBS Program Goals



Provide enabling technology and tools to reduce commercial energy use and demand by 20% beyond business-as-usual, by:

- **Developing & deploying energy saving technologies, strategies, and techniques**
- **Improving commercial building design, commissioning, and operating practices**
- **Improving the health, comfort, and performance of occupants**
- **Conforming to sound economic investment practices**

National Crosscutting “Big Issues”



- Impacts of new building systems, technology
- “Digital everything”/ubiquitous computing, sensing...
- Risk and slow diffusion rates: market push and pull
- Technology focus vs. people focus (designers, owners, occupants...)
- Changing Perspective: Occupant <-> Building <-> Grid
- Building life cycle perspective
- Process issues and Decision support tools - explicit and implicit energy decisions
- Information technology: data, tools
- Performance metrics and benchmarks
- Energy/Demand/\$\$ focus --> Green Buildings focus
- Sustainability, persistence over time

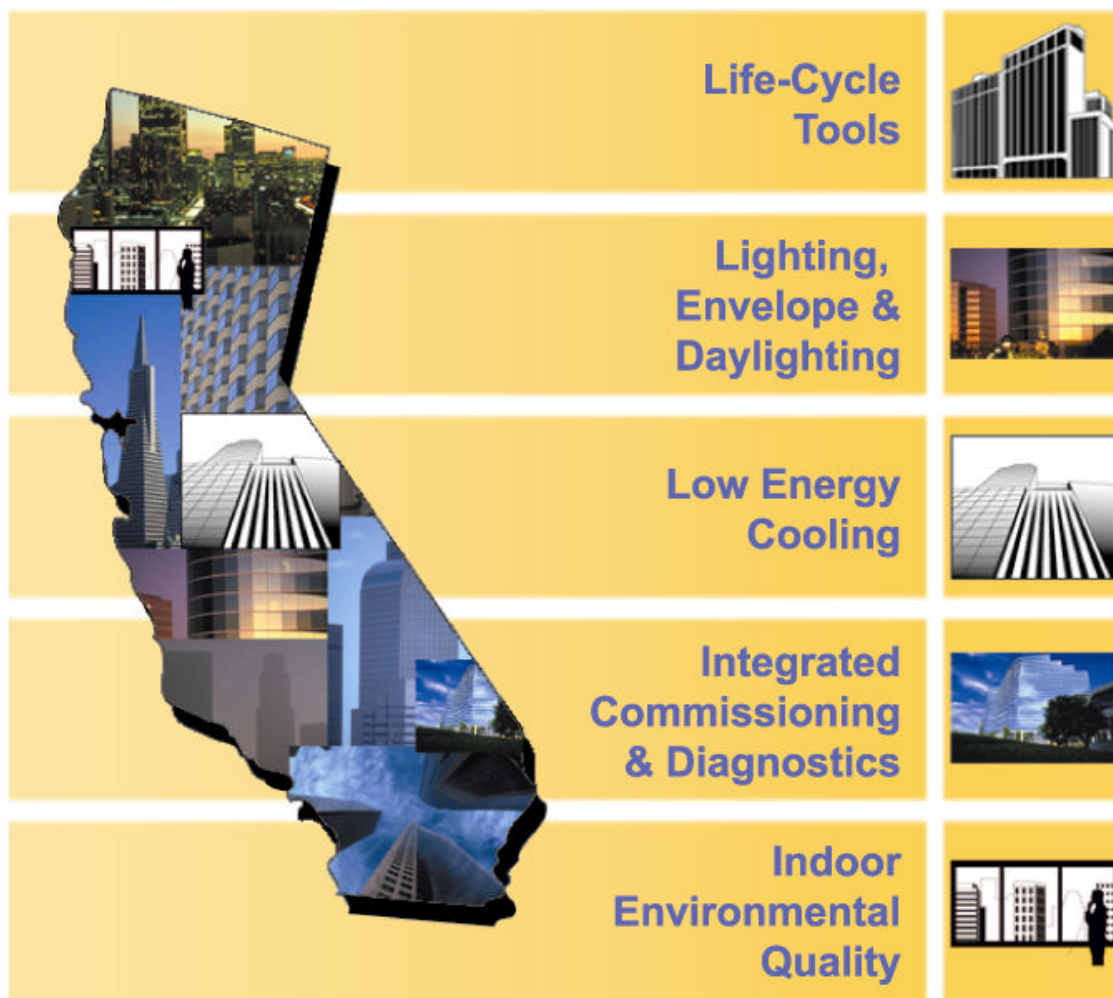
California Program Context



- **PIER R&D <--> Deployment <--> Market Impacts**
 - CEC Building Standards
 - Utility programs, CPUC programs
 - State - Regional - National deployment programs
- **“Summer of 01”- CPP and demand response**
- **Disaster/Hazard Response - Post 9/11 world**
- **Internet boom/bust and California economy**

Program Organization

- 5 Interrelated Technical Elements



Program Advisory Committee



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US Department of Energy
New Buildings Institute
SCE
PG&E
AEC

Program Impacts



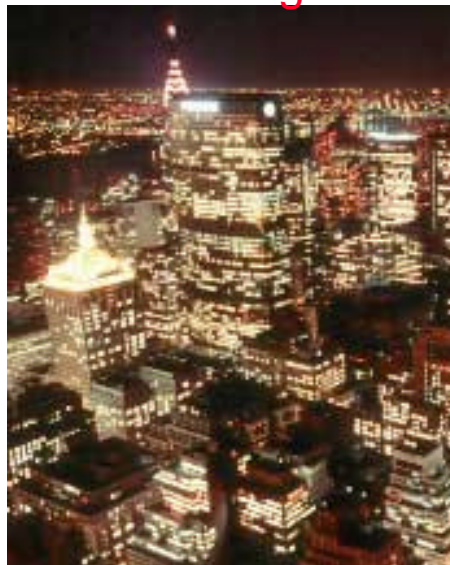
NY Times HQ- El. 3



SF Fed building –El. 4



Benchmarking
Your Building- El. 2



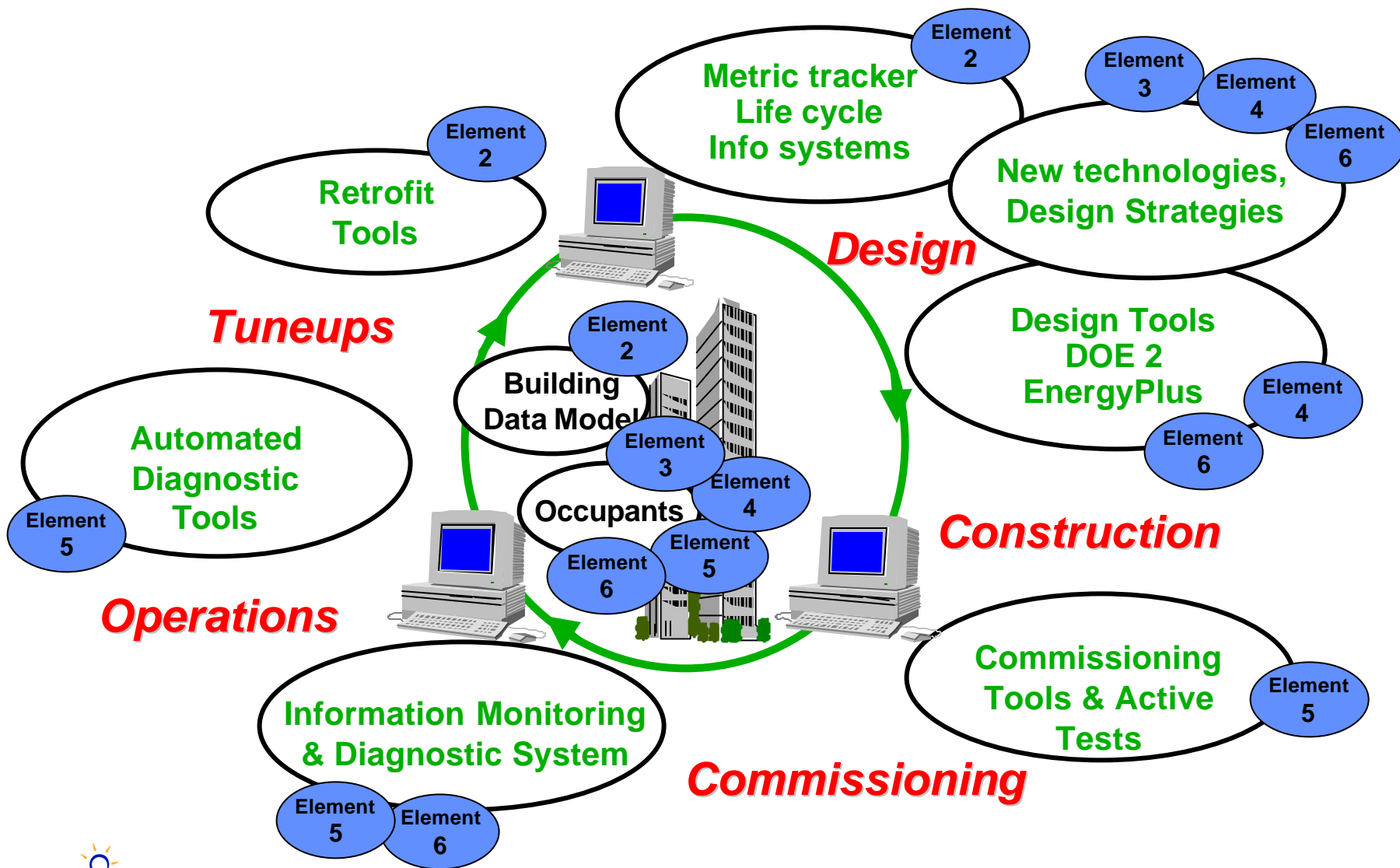
Portable Classrooms- El. 6



Oak Fed building-El. 5



HPCBS Seen in a Life-Cycle Performance Perspective



Status



- **Completed Program Technical Work**
 - 5 Elements, 14 Projects, 42 Tasks
 - Significant progress and accomplishments
- **Guidance: sponsors, partners, TAG, PAC**
- **Output: 100+ reports, briefings, tools, conference presentations...**
- **Access, outreach:**
 - CD, public web site
 - Papers, guides, codes, conferences, utilities, meetings...
- **Follow-on market impacts**
- **Follow-on technical work**

Today's Briefing



- **Technical Progress**
 - Captured in detail in final report, website
 - Navigating through \$6M information resource
- **Feedback on Accomplishments**
 1. More information on results
 2. Your access to results
 3. Market push/pull for greater market impacts
 4. How to extend results
 5. Missing pieces?

- **Strategic Communications**
 - Articles in key industry publications
 - Technical publications: researchers, advanced users
 - Website: new public site
 - Conferences
 - Professional involvement: Title 24, ASHRAE, collaboratives (CHPS, CEE, CCC...)
- **Specific partnerships, demonstrations**
 - Utility collaborations - CTAC, PEC, ETCC,...
 - DOE, DOD, GSA, other private/public
 - CA: CPUC, CHPS, DGS, UCOP,...

Program Website



High Performance Commercial Building Systems - Netscape

High Performance Commercial B...

High Performance Commercial Building Systems

[What's New](#) | [Publications](#) | [Partners](#) | [Glossary](#) | [Site Map](#) | [Links](#) | [Contact Us](#)

Commercial buildings account for about one-third of all California electricity consumption, at an annual cost of \$9 billion. Although aggressive efforts by California to improve building design have led to significant increases in commercial building energy efficiency over the past 20 years, the savings are still well below technical and economic potential.

A three-year public-private research initiative, which targets substantial reductions in the energy costs of commercial buildings, under the leadership of scientists from the U.S. Department of Energy's Lawrence Berkeley National Laboratory is close to completion. More than \$9 million in research, development, demonstration and deployment funding has been provided by the California Energy Commission through its Public Interest Energy Research Program, along with the Department of Energy and private sector partners who provided in-kind assistance.

What's New

To browse the HPCBS Web Site, you can use one of the four targeted site maps for Commercial Building Professionals or you can proceed to the [HPCBS Program Overview](#) page and browse the entire web site.

User Communities

Design Professionals
Choose a place to go:

Manufacturers
Choose a place to go:

Owners and Building Managers
Choose a place to go:

Schools/School Districts
Choose a place to go:

Search
Enter some key words to search by:

General Topics

Advanced Relocatable Classrooms

- [Relocatable Classrooms & Indoor Air](#)

Facility and Energy Management

- [Building Retrofit Analysis](#)
- [Fan Diagnostics](#)
- [Interoperability for Computer Assisted Design \(CAD\)](#)
- [K-12 Schools & Small Commercial Benchmarking](#)
- [Load Monitoring Based Fault Detection Diagnostics](#)

Facility and Energy Management con't

- [Monitoring with Energy Management Control Systems](#)
- [Obtaining Feedback from Occupants](#)
- [Performance Metrics for Building Life Cycle](#)
- [Persistence of Commissioning Savings](#)
- [Review of Diagnostic Tools & Energy Information Systems](#)
- [Simulation Assisted Commissioning & Monitoring](#)
- [Tools for Commissioning New Construction](#)
- [Web-Based Benchmarking](#)

Lighting and Daylighting Controls

- [Daylighting & Electrochromic Windows](#)
- [Networked Lighting Controls](#)

Space Conditioning Systems

- [Efficient HVAC Distribution](#)
- [Low Energy Cooling Model Development](#)
- [Low Energy Cooling Systems](#)

Last updated May 27, 2003

Document: Doms (0.415 secs)

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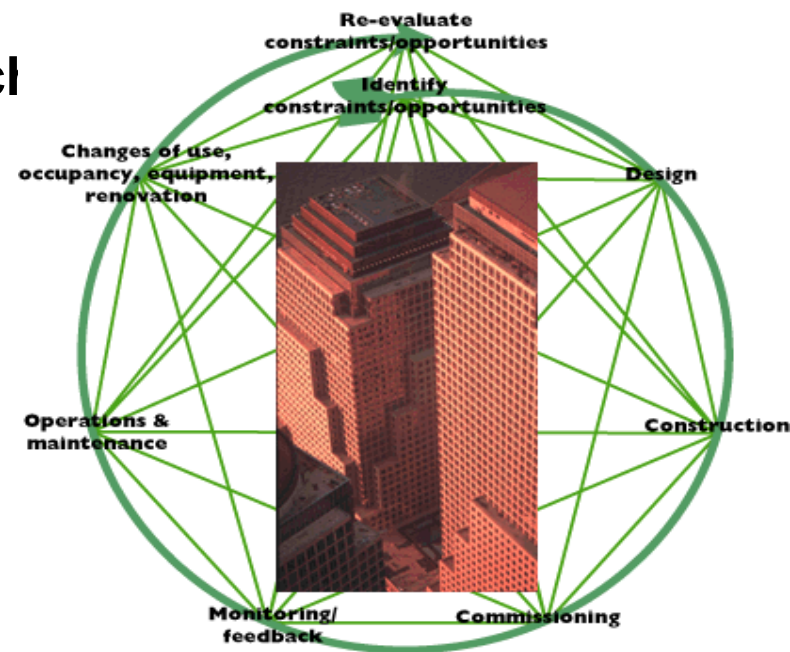
Website: <http://buildings.lbl.gov/hpcbs>

Element 2 Overview

Life-Cycle Tools



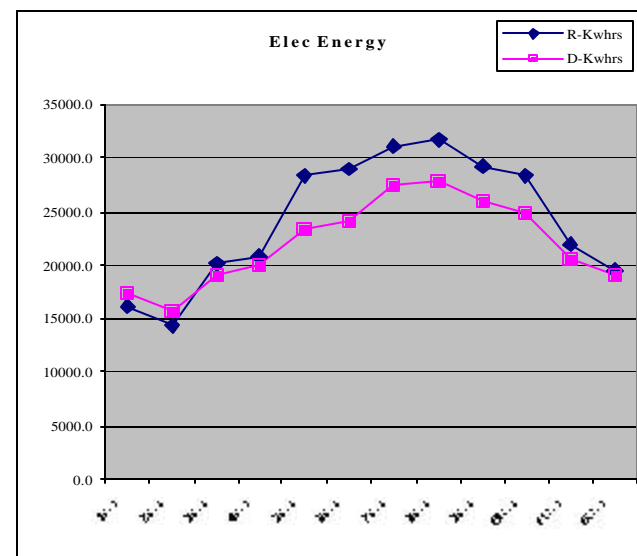
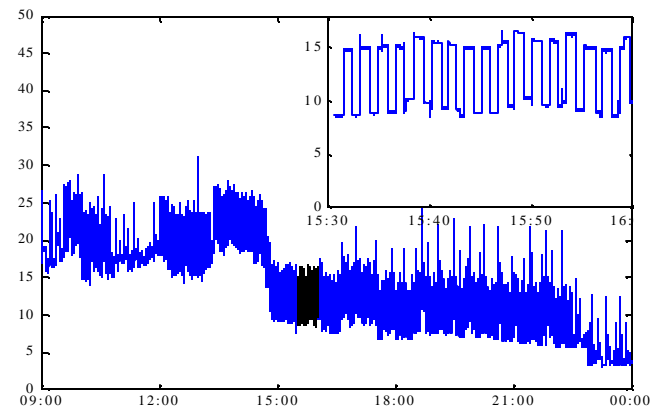
- Goal: Develop integrated information management technologies to assist in improving commercial building performance
- Problem: Information fragmented & incomplete as it flows through building life cycle, current tools limited
- Projects
 1. Performance Metrics & Benchmarks
 2. Retrofit Tools
 3. Interoperability
- Team
 - LBNL
 - MIT
 - Silicon Energy
 - EPA
 - GSA



Element 2 Projects and Tasks



- Web-based Benchmarking Tool
- Performance Metrics Tracking Tool
- **Benchmarking with High-speed Electrical Monitoring**
- **Retrofit Energy Savings Estimation Method**
- Interoperability for HVAC Schema



Benchmarking Background



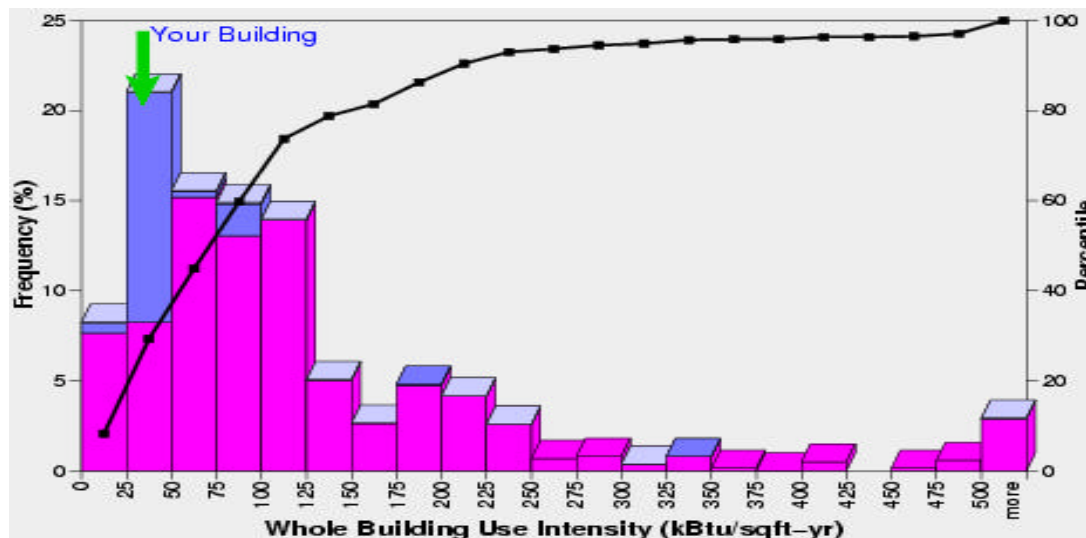
Benchmarking: **Process of comparison against standard or average**

- Why Benchmark?
 - **Determine how well a building is performing**
 - **Set targets for improved performance**
 - **Facilitate assessment of property value**
 - **Gain recognition**
- Why Use Regional Tools?
 - **Climate is main source of variation**
 - HDD, CDD, humidity
 - **Varying codes, incentives**
 - **Different fuels, prices**
 - **Most existing tools based on CBECS**
 - **Finest geographic resolution is Census Division**

Benchmarking and Cal-Arch



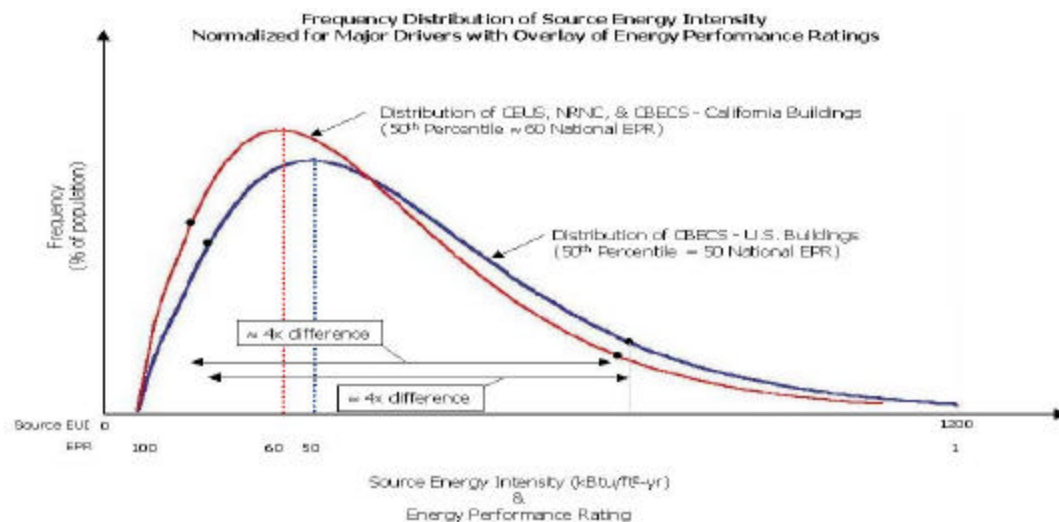
- Accomplishments
 - Collaboration with EPA/CEC, industry, utilities, public workshops
 - ACEEE and ECEEE papers
 - Finalized online tool based on CEUS
poet.lbl.gov/cal-arch



Benchmarking and Cal-Arch

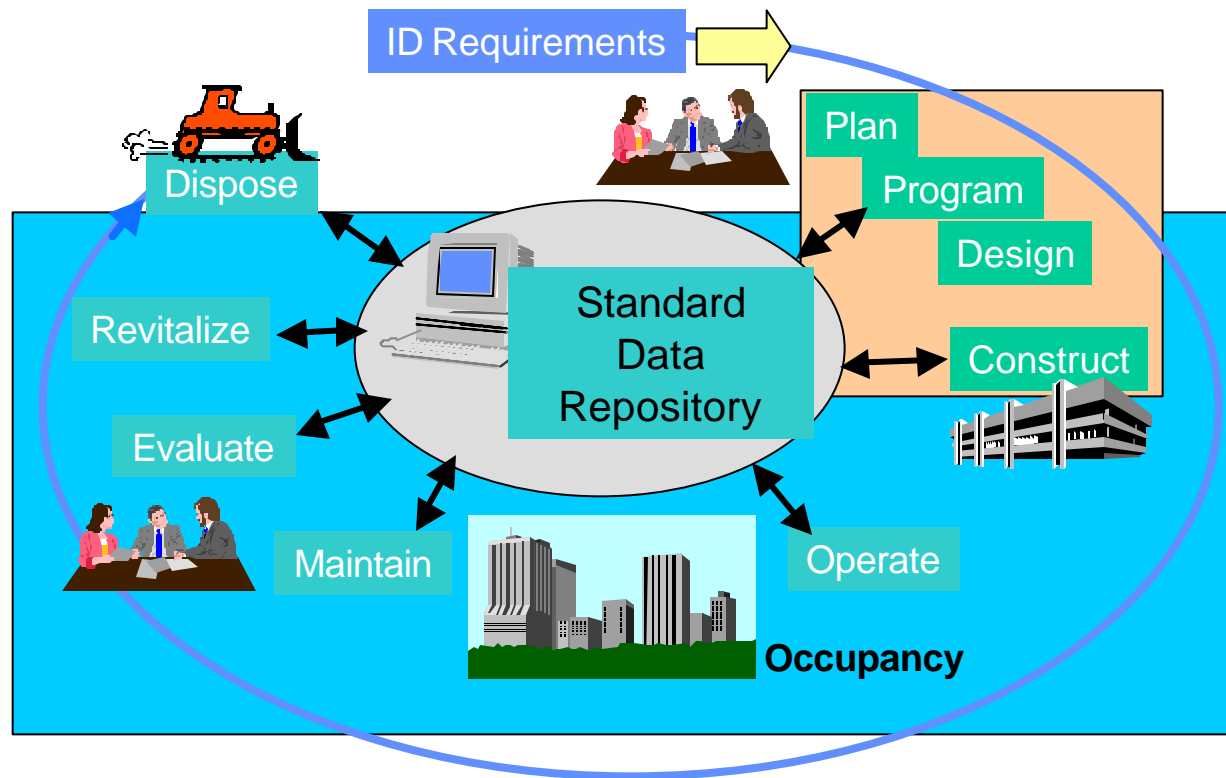


- Next Phase
 - Collaboration with California High Performance Schools Collaborative (CHPS)
 - Additional work with EIS companies
 - Future CEUS benchmarking
 - Collaboration on Energy Star



Interoperability Background

- Data acquisition from upstream participants & tools
- Data archival for downstream participants & tools



Interoperability Data Standards

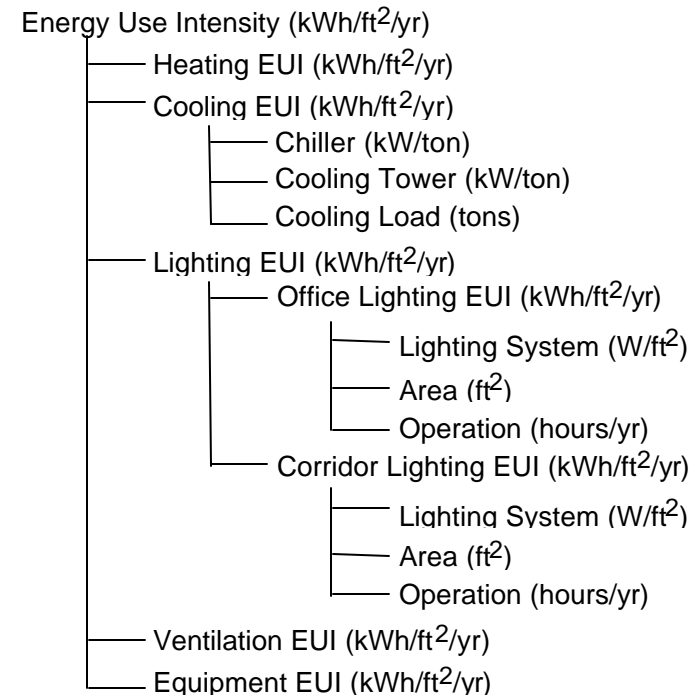
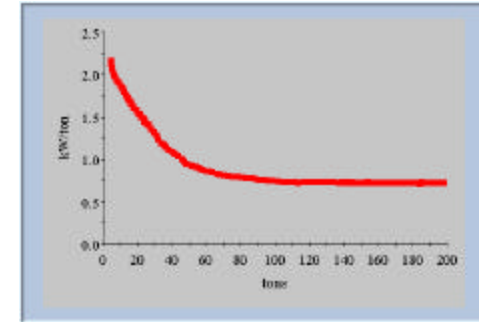


- Object Data Model
 - **Object-oriented model of the entire building**
 - Elements (e.g., Walls) and Relationships (e.g., Walls->Space)
 - **Archive and exchange complete project data set**
 - **Industry Foundation Classes (IFC)**
- Internet Data Exchange Models
 - **Extensible models of data subsets**
 - Product libraries (e.g., Chillers)
 - **Exchange of product and other data subsets to support transactions over the Internet**
 - XML: aecXML, ifcXML

Data Archive for Downstream Applications



- Building and System Design Performance
 - **Expected Loads**
 - **Equipment Performance**
 - **Design Performance Benchmarks**
- Simulation Context Data
 - **Occupancy & Usage**
 - **Thermal Zoning**
 - **Building Systems Operation**
 - **Weather**



Metracker Software



The screenshot shows the Metracker software interface with the following components:

- Building Version (IFC data file):** Points to the 'Example Project' window.
- Product Model Hierarchy:** Points to the 'Example Project' window.
- Performance Model Hierarchy:** Points to the 'Example Project' window.
- Performance Objective:** Points to the 'Performance Objective: Optimize Energy Performance' node in the hierarchy.
- Performance Objective Child:** Points to the 'Performance Objective: Whole Building Energy Use' node in the hierarchy.
- Performance Metric:** Points to the 'Performance Metric: As-Operated 1999 Whole Building Monthly Electric EUI' node in the hierarchy.
- Properties and Values of Selected Object:** Points to the table on the right side of the interface.

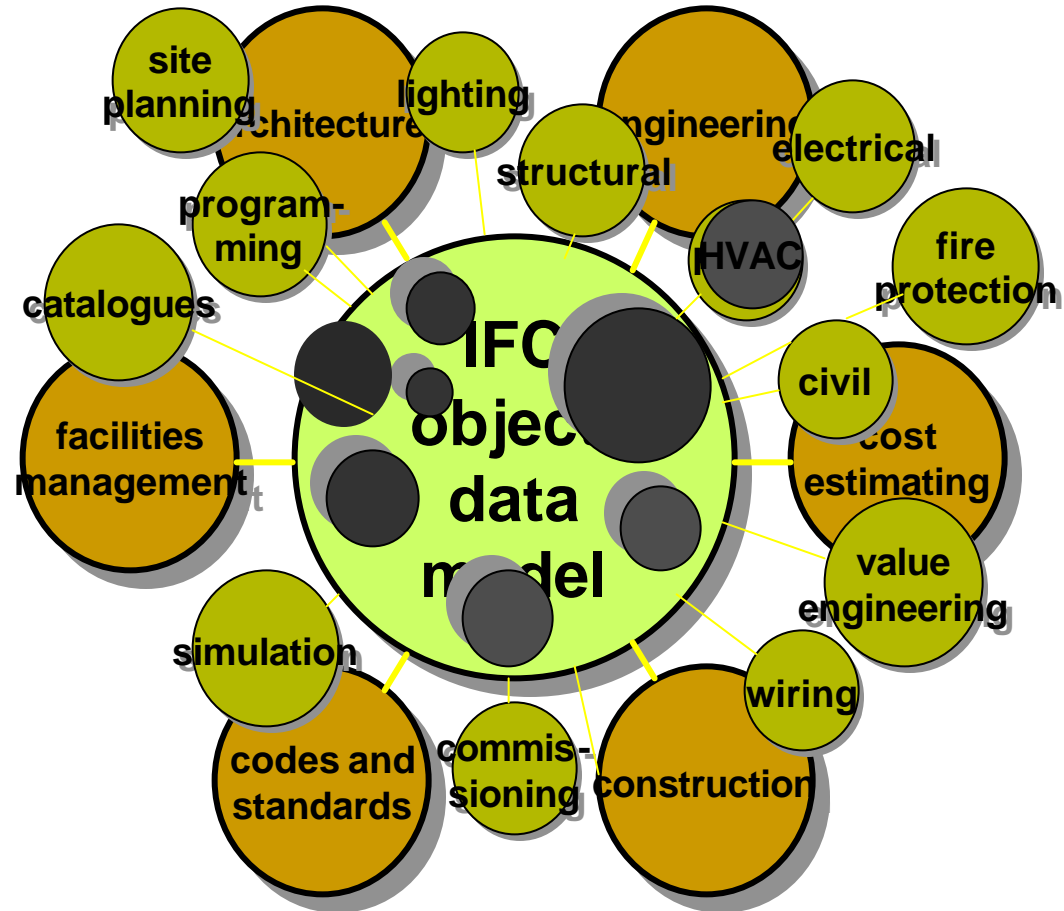
Property	Value
Name	Optimize Energy Performance
Unique ID	zseg\$wiZje6~LfrcuD&9
Specifier Index	0
Application Index	0
Date of Specification	July 31, 2001
Description	Reduce design energy cost cor
Objective Type	energy
Parent GUID	JQ#Z=9m,FeMuHKEoON6,

- Accomplishments & Next Steps
 - Prototype tool, produced papers & presentations
 - Collaboration with GSA and IFC Community

Interoperability & Industry Foundation Classes



- Extended IFC schemata to support modeling HVAC systems
 - Design <-> Operations
 - Begin Implementation
 - Participants: **7 organizations in 5 countries**
 - Government: **Australia, EU, Finland and U.S., federal and state**
 - Private: **Finnish & French**



Interoperability & Industry Foundation Classes



- Accomplishments
 - Supported use of simulation tools
 - Import information from upstream applications, e.g. CAD, in *.ifc or XML format (Building geometry, materials, etc.)
 - Export information to downstream applications in *.ifc or XML format
- Next Steps
 - Continued implementation with tools vendors, demonstrations and cooperation with IAI members



Element 3 Overview

Lighting, Envelope & Daylighting



Goal: Develop an integrated building equipment communications network (IBECS) that will provide Internet-based control of lighting, daylighting and envelope systems

Problem: The high cost and complexity of integrated lighting and building envelope systems has limited market penetration

Projects

- Lighting Controls
- Daylighting & Envelopes
- Network Operations

Team

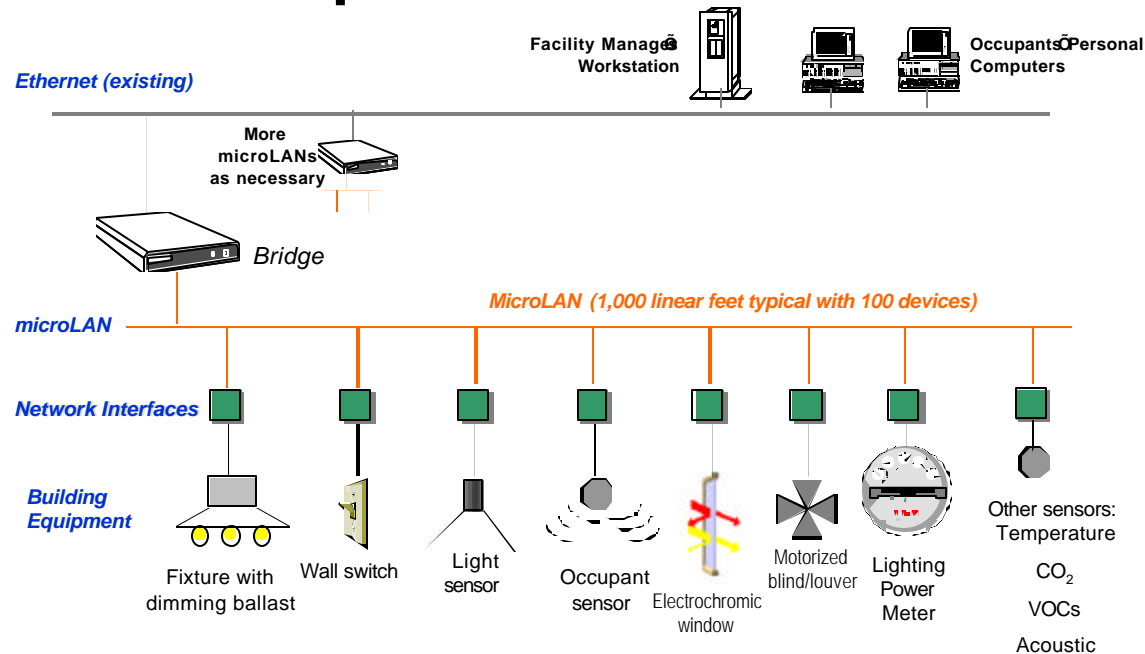
- LBNL
- Vistron Corp.



Element 3 Selected Major Tasks



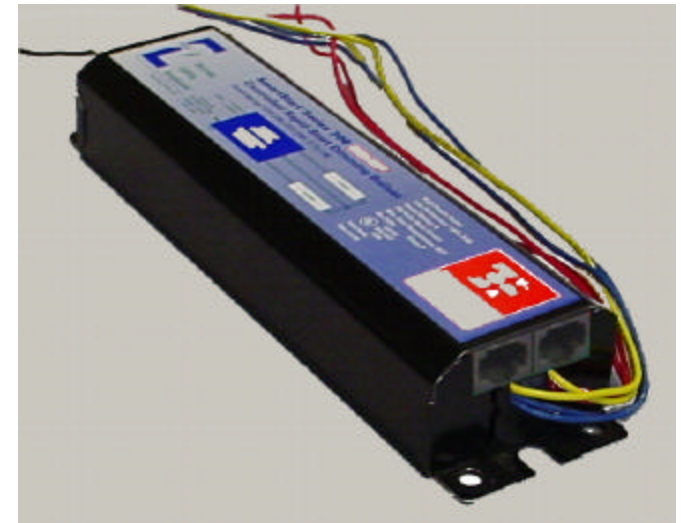
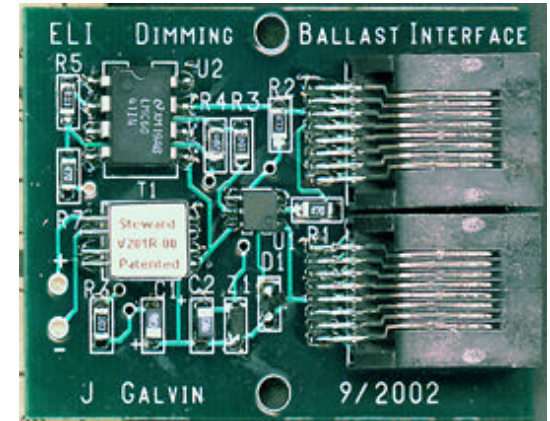
- Build and test key IBECS lighting components
- IBECS controlled motorized blinds and electrochromic windows
- Build demonstration network
- Communication protocol framework



Build and Test Key IBECS Components



- Accomplishments
 - Successfully developed and tested IBECS ballast interface and addressable switch
 - Developed prototype environmental sensor
 - **Demonstrated Powerline Carrier for switching lighting loads in existing buildings**
- Next Phase
 - Work with manufacturers to embed IBECS in control devices
 - Demonstrate advantages of digital control to early adopters



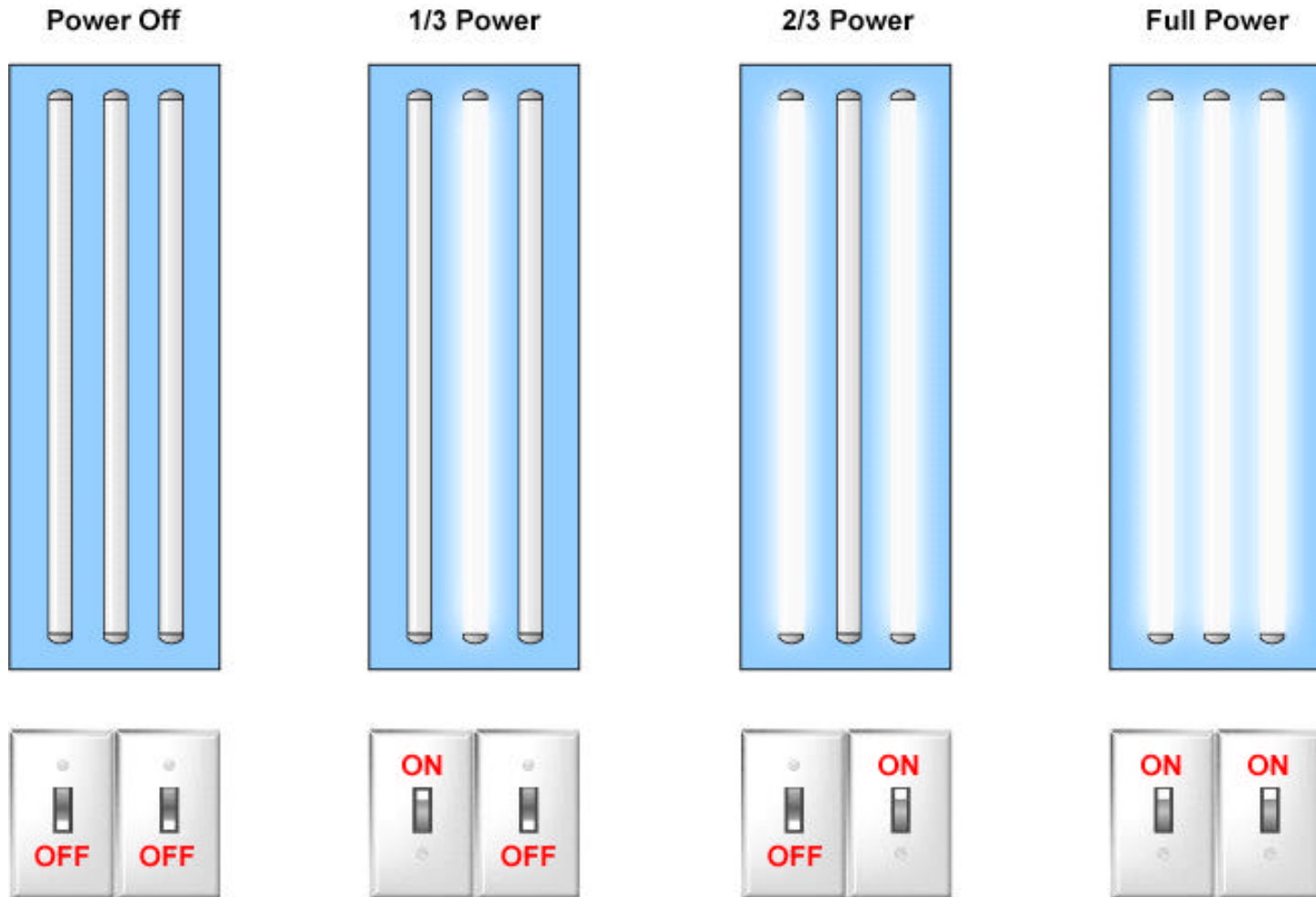
Addressable Wall Switch

Title 24 Wall Switch

- Produced IBECS-addressable switch “proof-of-concept”
- Demonstrated off-the-shelf solution for controlling lighting relays *in existing CA buildings* using Power Line Carrier (PLC)
- Solution addresses the huge load represented by all the bi-level switches installed in California commercial buildings since 1982



Bi-Level Switching: **How It Works**



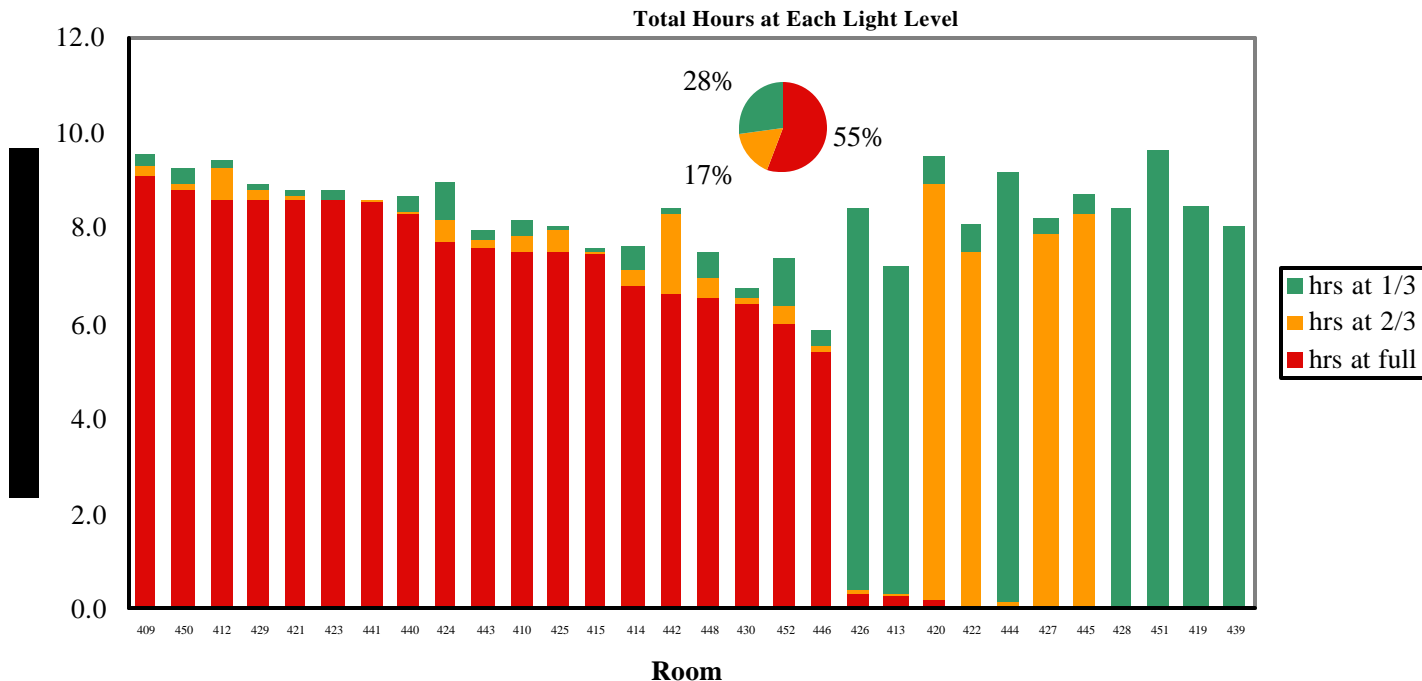
Bi-Level Switching: How It Works

One switch operates the outer two lamps while the other operates the inside lamp

Bi-Level Switching Works!



Average Number of Hours Per Day At Three Different Light Levels

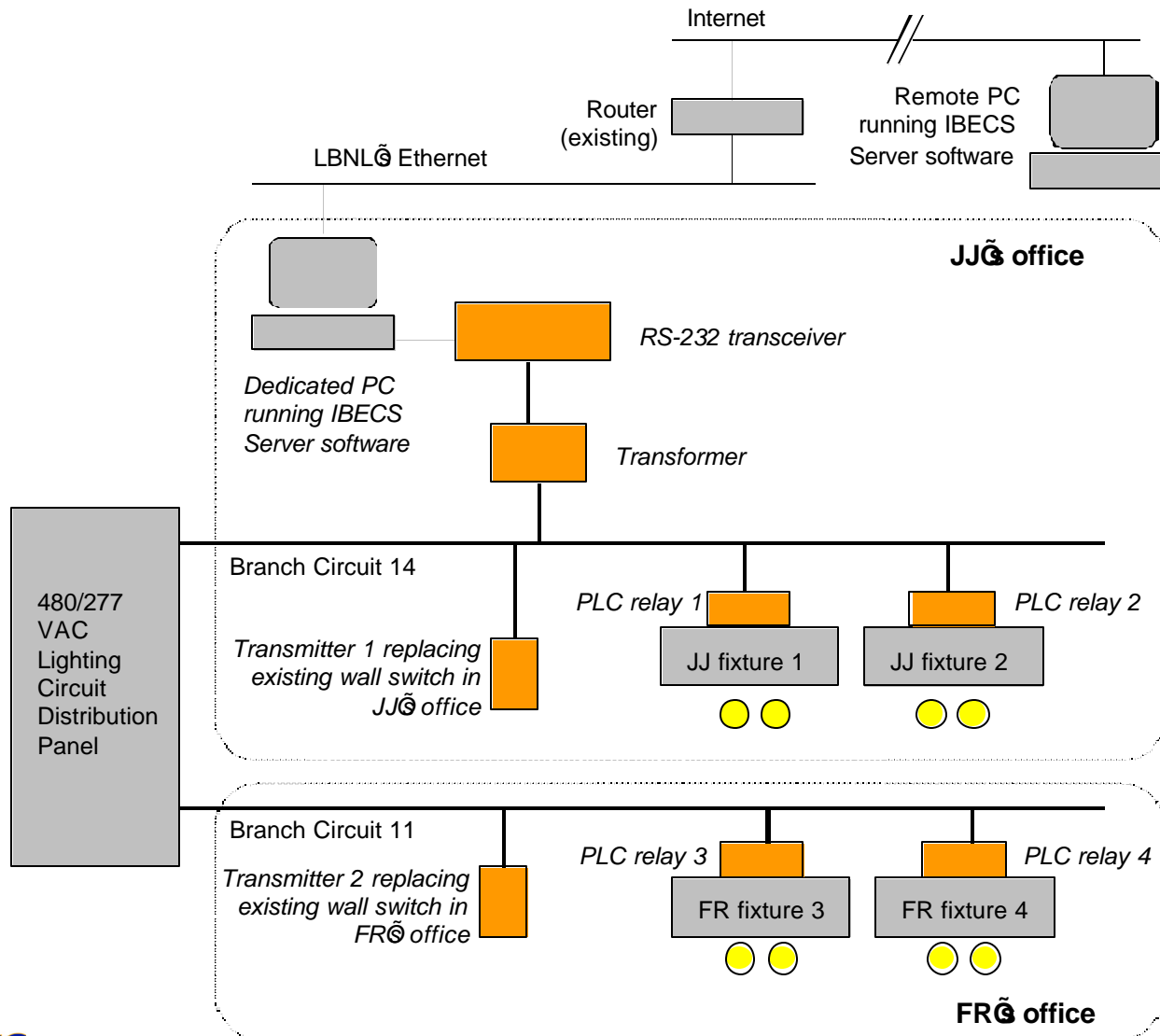


- Occupants use bi-level switches *effectively*
- Reduced lighting energy by 20-25%

30 perimeter offices over 7 months

Imagine the possibilities for remote control

Demonstrating Powerline Carrier Switching System



Lessons Learned from the PLC Demonstration



- Today's powerline carrier is much improved over yesterday's
 - PLC is one appropriate method to enable remote control of most bi-level lighting loads in existing CA buildings
- Other methods are also appropriate, including RF and improved PLC methods
- We should use existing wiring as the basis for communicating with lighting loads ***in existing buildings:***
 - *Load shed* ballasts
 - Intelligent relays (leverage CA's historic investment in bi-level switching)

IBECS Controlled Motorized Blinds and Electrochromic Window

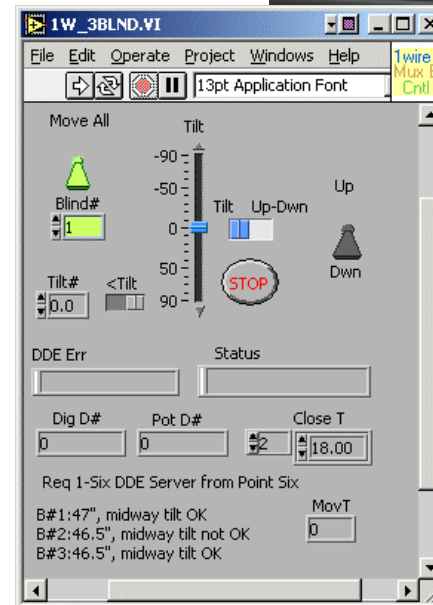
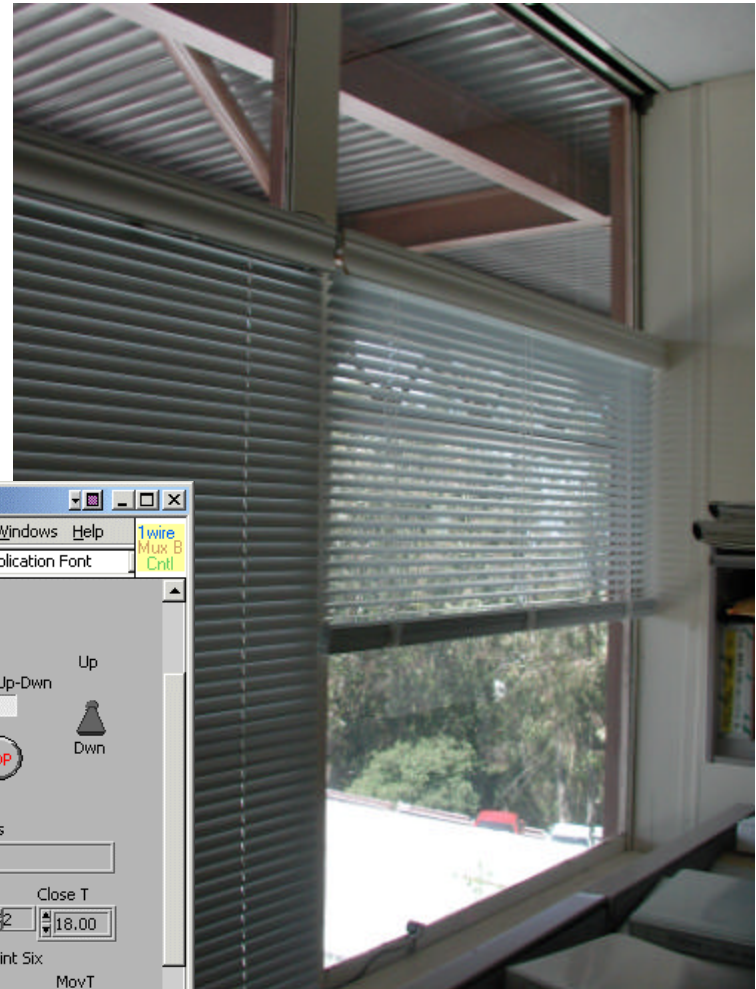


Accomplishments

Demonstrated feasibility of IBECS for controlling motorized blinds and EC windows

Engaged shade device manufacturers about adopting IBECS

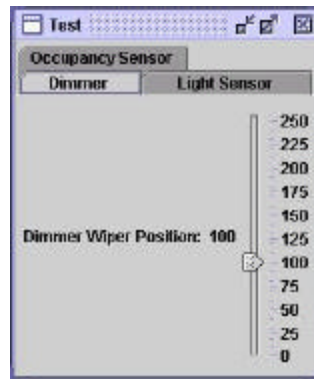
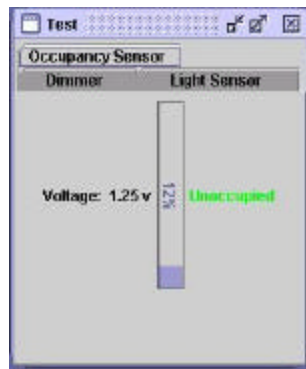
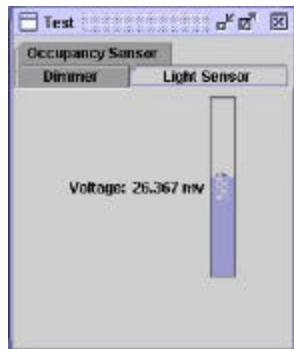
Initiated integrated shade and dimmable lighting demo at NY Times mockup



Build IBECS Demonstration Network



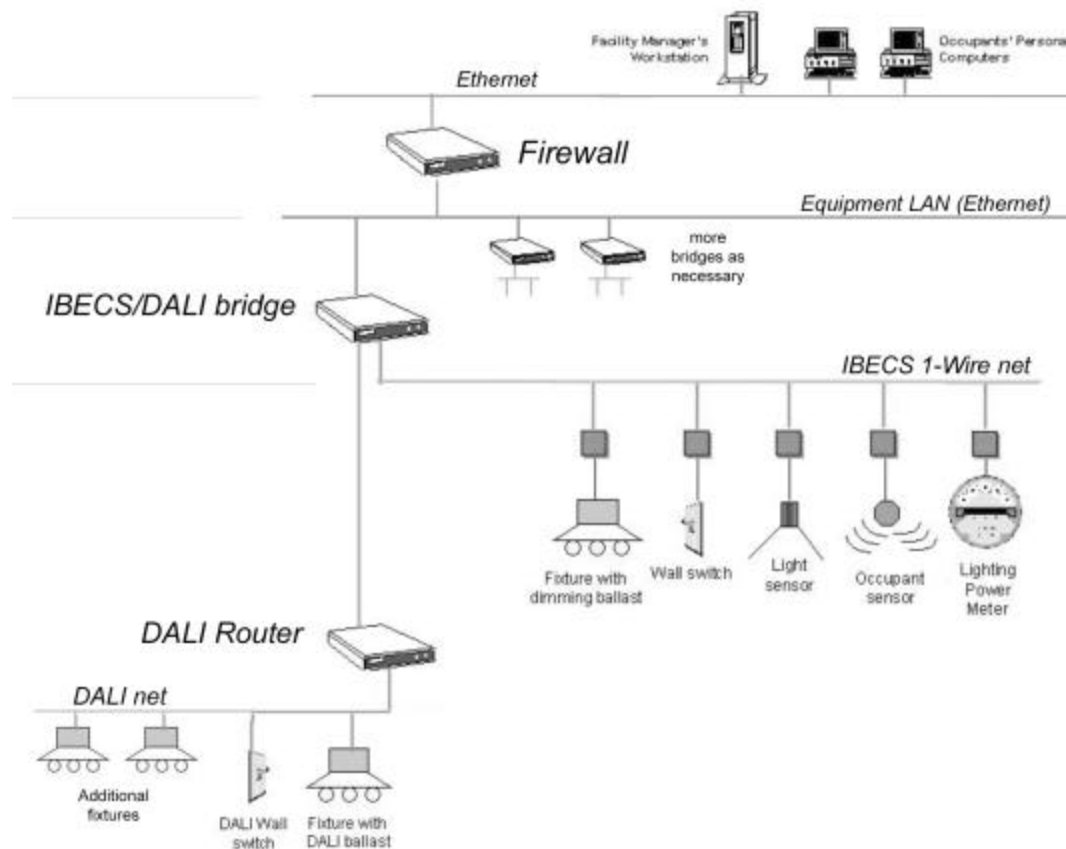
- **Accomplishments**
 - Installed demonstration network of IBECS prototypes at LBNL
 - Produced rudimentary software for reading and controlling attached devices
 - Improved sensors so external power unnecessary



Framework for Unifying Digital Communication Protocols



- **Accomplishments**
 - With NIST, developed framework that unifies BACnet, DALI and IBECS
 - IEEE paper: “Standardizing Communications Between Lighting Control Devices”
- **Next Phase**
 - Work with manufacturers of DALI products to combine IBECS sensing with DALI net control of digital ballasts



Lessons Learned



- Importance of engaging manufacturers
 - Embedding technology into existing products lowers cost of deployment
- Need to work with and complement DALI
 - Only digital protocol accepted by major ballast companies
 - Physical compatibility (two wires, not four)
 - Commissioning is barrier to all digital controls
- Need to integrate with BACnet
- Software development is expensive
- Need cadre of software developers to write cool software
 - Open standards

Sitting on a Gold Mine



- Title 24's "bi-level" switching requirements in place in CA commercial buildings since 1982
- The lighting energy consumed in CA offices, retail, foodstores and miscellaneous is 15 BkWh/yr
 - Equivalent to 4.7 Gigawatts
- There is 1 - 1.5 Gigawatts of lighting load that could be shed without affecting productivity or comfort
 - Economic value: *\$1 billion!*
- We propose using intelligent relays and PLC-type control to mine this power source in CA commercial buildings

Element 4 Overview – Low Energy Cooling

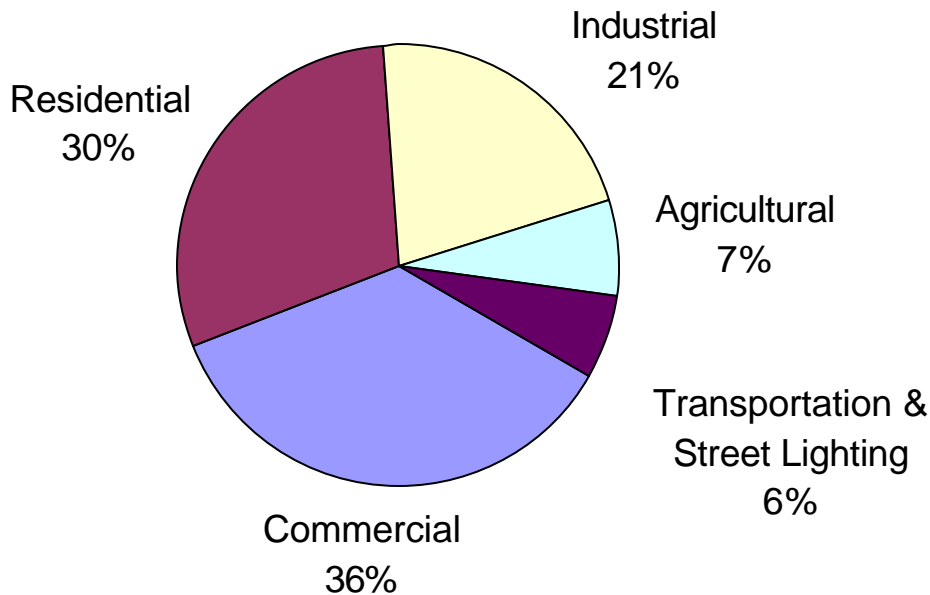


- **Goal:** Reduce cooling energy use and peak demand
- **Problem:** Complexity and risk associated with Low Energy Cooling strategies; lack of tools, code acceptance
- **Projects**
 1. Appraisal of System Configurations
 2. Model Development
 3. Efficient Thermal Distribution Systems - Ducts
- **Team:**
 - LBNL
 - UC San Diego
 - Arup
 - Flack+Kurtz

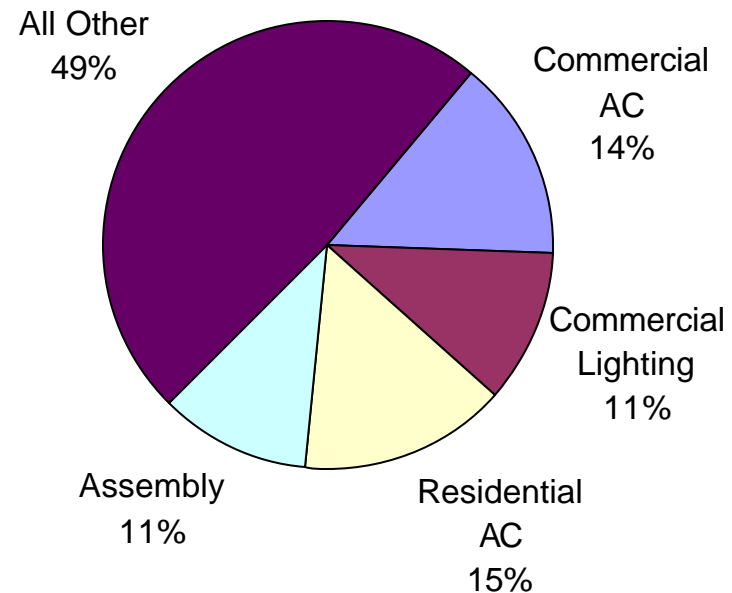
Appraisal of System Configurations: Problem Statement



Electricity Use



Peak Demand



Conventional cooling systems are energy intensive and contribute to peak demand, yet do not exploit California climate conditions

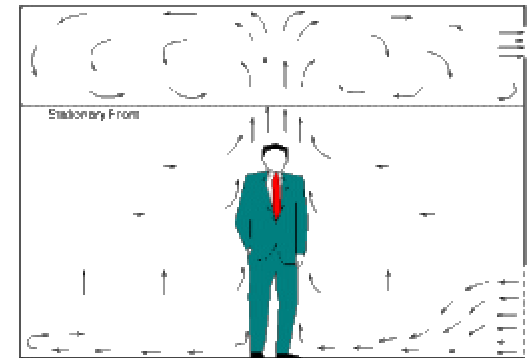
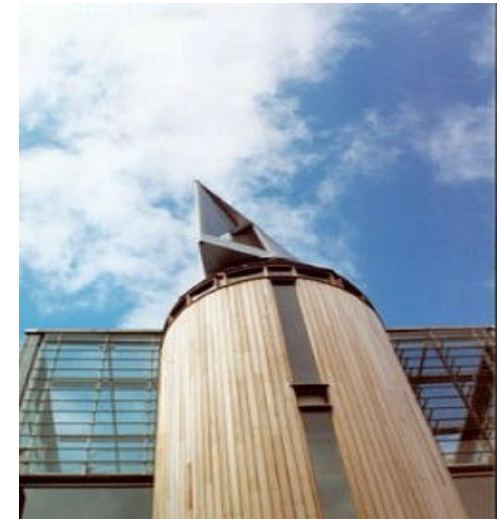
Objective: identify combinations of low energy cooling strategies and technologies that have significant potential for California

Appraisal of System Configurations: Approach



System Design Strategies

- Eliminate or reduce chiller use
 - **evaporative cooling, natural ventilation ...**
- Cool spaces more effectively
 - **displacement ventilation, radiant cooling ...**
- Shift/smooth peak demand with thermal mass
 - **exposed slabs, raised floors**
- Improve distribution systems
 - **hydronic systems inherently more efficient**



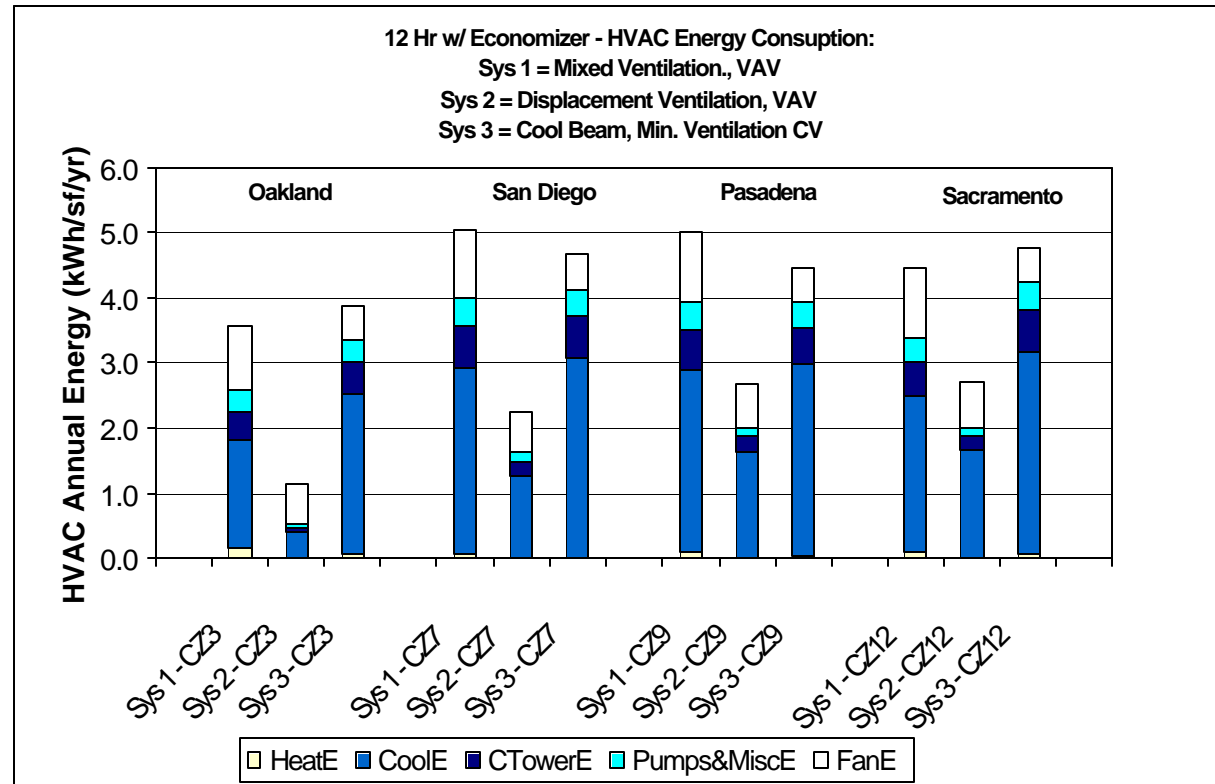
Use simulation to assess the potential of different strategies in different climates and building types

Appraisal of System Configurations: Results



DOE-2 Results

- **Displacement ventilation:** major savings (30-60%), more with indirect evaporation, especially in hotter climates
- **Chilled ceilings** reduce peak demand by reducing fan power, no energy savings without water-side free cooling



EnergyPlus Results

- **Displacement ventilation results less dramatic but still show significant savings**

Model Development: Problem



- Cooling technologies with promise for California can not be modeled adequately in DOE-2 and other energy simulation programs:
 - Displacement ventilation
 - Natural ventilation
 - Radiant slab cooling
- EnergyPlus is the most suitable platform

Objective: develop new models for low energy cooling simulation and implement in EnergyPlus

Model Development: Approach



Develop new room models that provide a first order treatment of the unmixed airflows that minimize cooling energy use:

- Displacement ventilation:
 - 2 layer model predicts:
 - temperature in occupied zone
 - return temperature
 - boundary height
- Natural ventilation:
 - cross flow: jet and recirculation regions
 - internal stack: stratification - 2 layer model

Implement in EnergyPlus and document for possible implementation in other programs

Model Development: Implementation



Flow model is selected each time-step...

Mixed

Stratified

Cross flow

**Displacement
vent. model**

**Recirculation
model**

**Single node
model**

**DV two node
model**

**CV two node
model**

....and is executed by EnergyPlus

Model Development: Outcomes

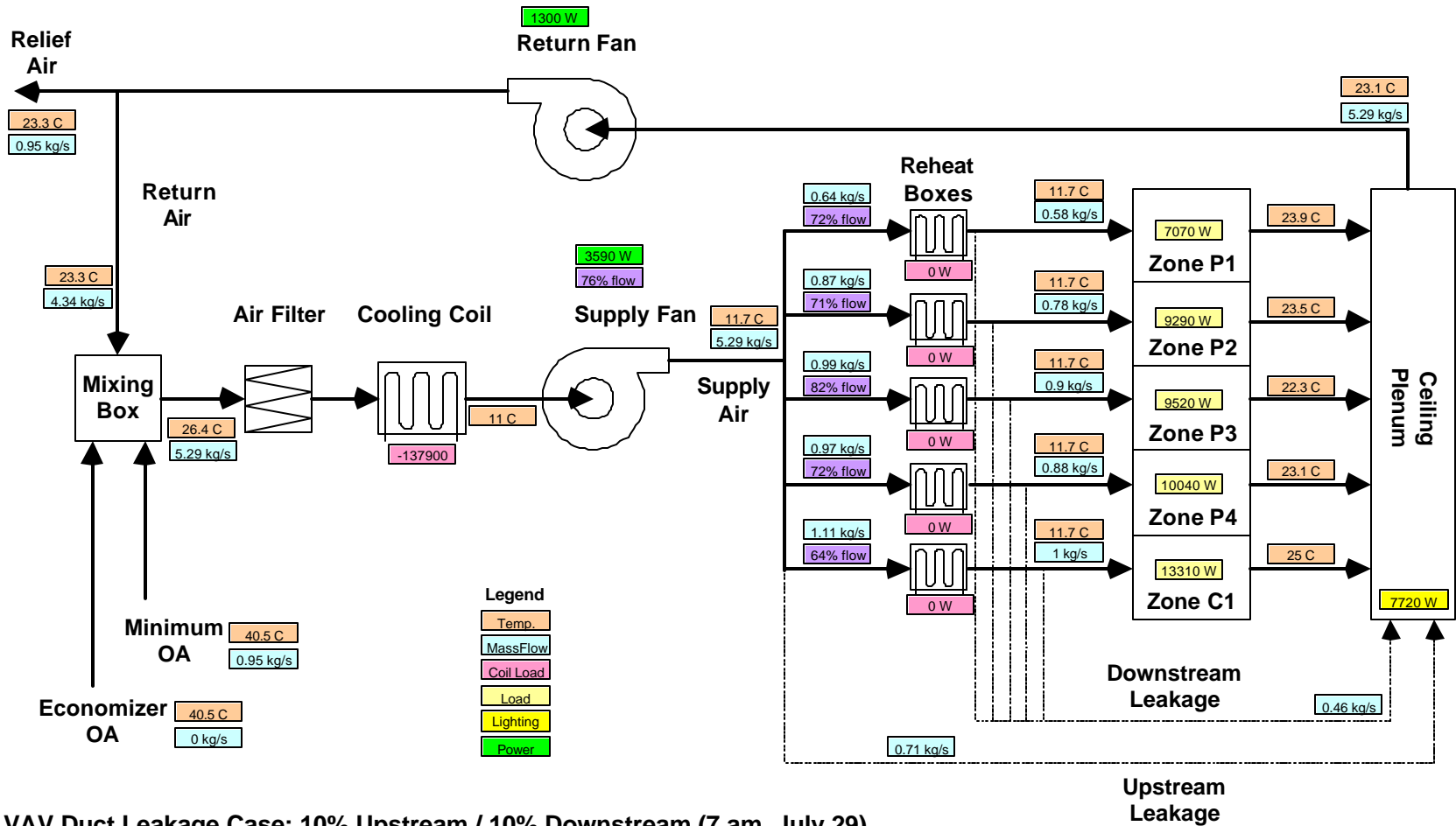


EnergyPlus models used in

- **design assistance:**
 - **new S.F. Federal Office Building:** natural ventilation, no mechanical cooling
 - **museum for San Diego**
 - **community college in San Jose**
- **system appraisal:**
 - displacement ventilation model predicts operating limits and provides guidance for designers



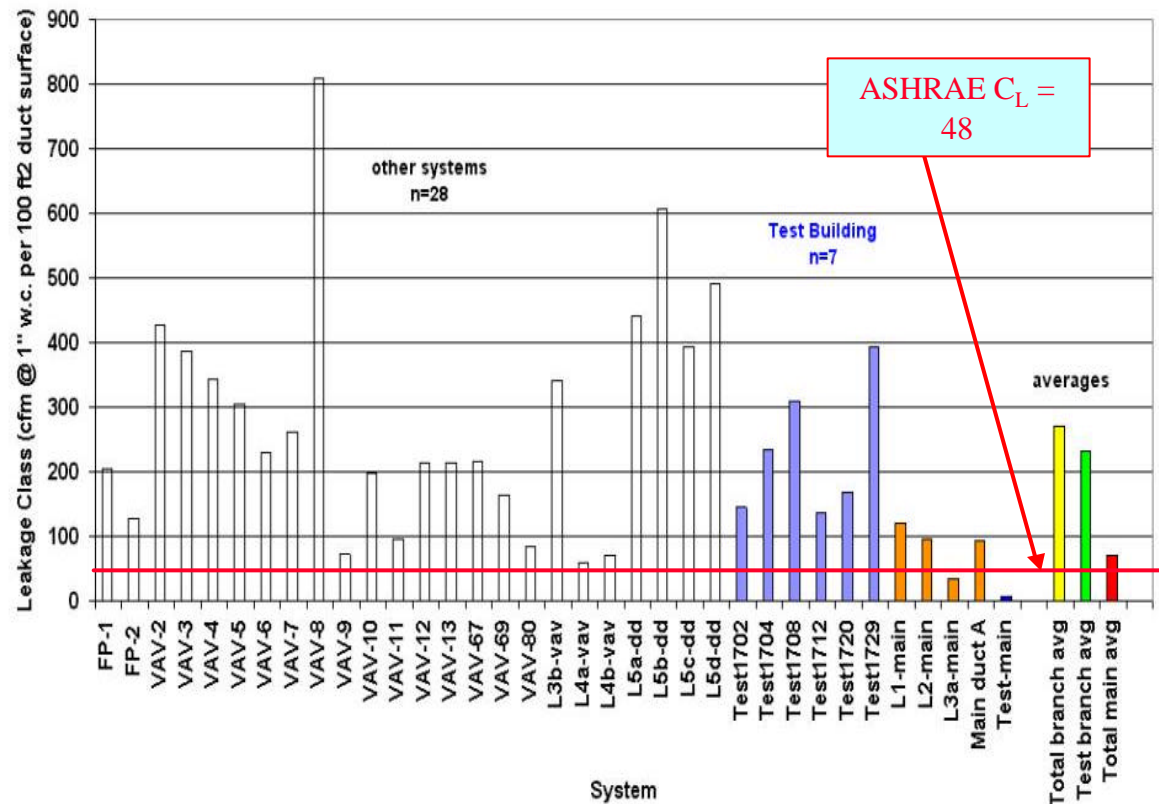
Efficient Distribution Systems



Leaky Ducts



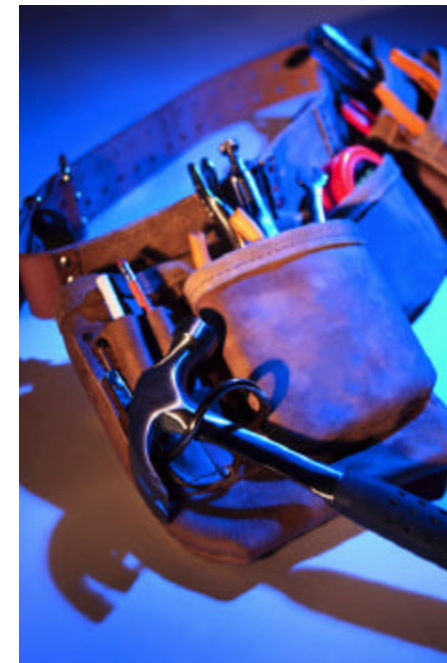
- **Background**
 - No T24 incentive for energy-efficient ducts in large commercial buildings
 - Potential leakage-related savings in CA: 560 to 1,100 GWh/yr fan energy + 100 to 200 MW peak demand
- **Objectives**
 - Develop simulation tools & metrics to support performance-based T24 compliance path



Addressing the Problem



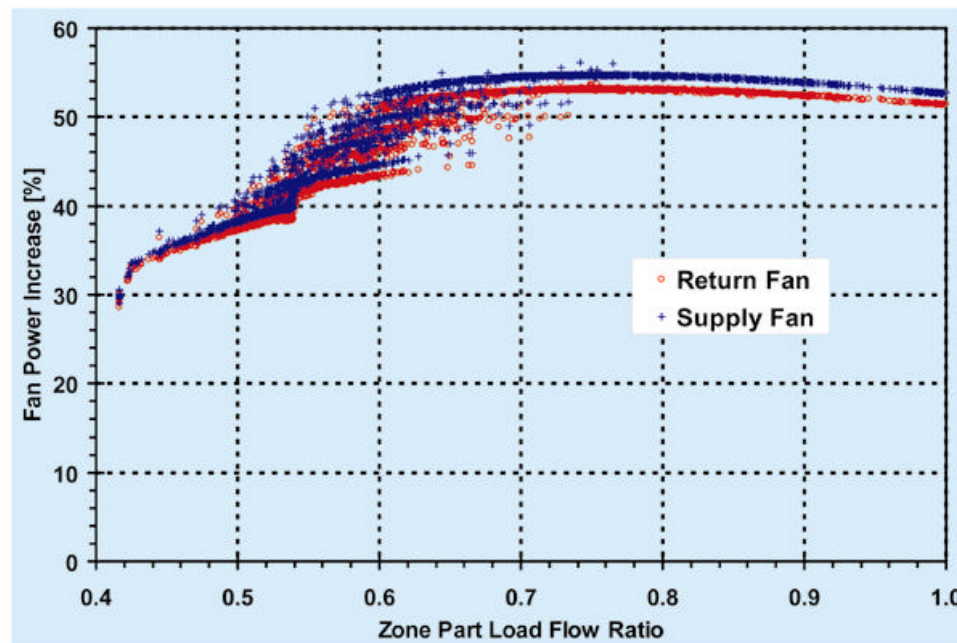
- **Provide Foundation for Compliance Tools**
 - Review duct modeling literature, identify short- & long-term simulation approaches
- **Extend Understanding of Leakage Impacts**
 - Use short-term approach to assess energy impact variability for 54 combinations of duct leakage, building vintage, & climate
- **Identify Efficient HVAC Systems**
 - Propose new T24 metric to compare systems
(e.g., air vs. hydronic, distributed vs. central)



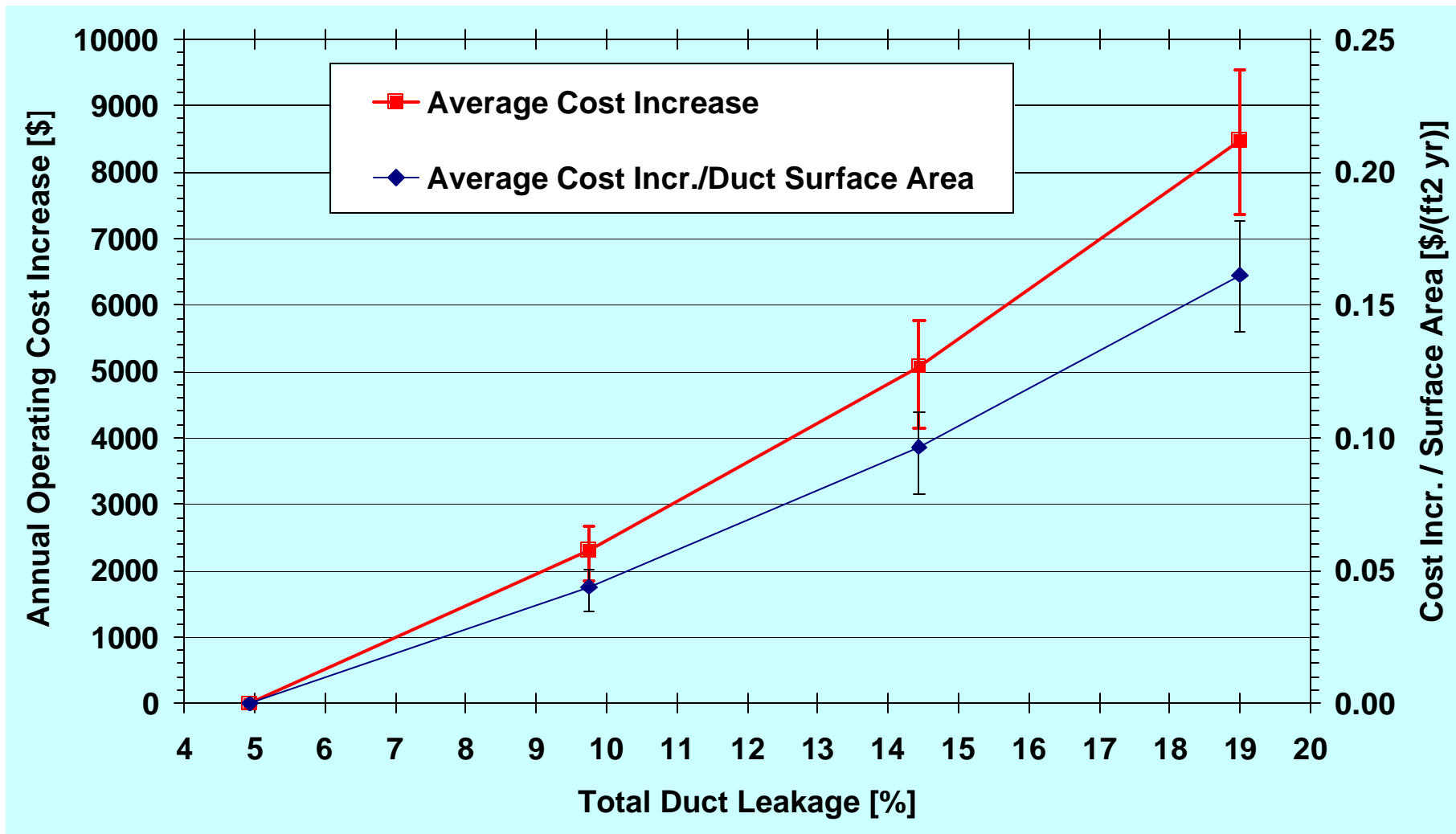
Project Results



- **Modeling Approaches**
 - Future: EnergyPlus;
 - Now: DOE-2/TRNSYS hybrid
 - Documented duct component models (TRNSYS)
- **Large Commercial Building Impacts**
 - Prescribe single duct leakage threshold in T24, independent of building vintage & location
 - Sealing duct leaks is cost-effective, at least for VAV systems with 10% or more leakage
- **Transport Efficiency**
 - New reporting requirement for 2005 T24 ACM



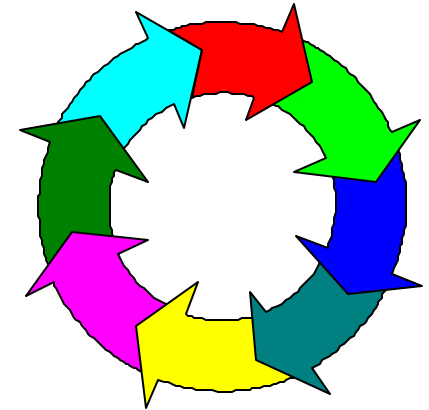
Sealing Ducts Makes Sense



Further Work – Industry Needs



- **Stock Characterization
& Energy Savings Potential**
- **Design & Construction**
- **Codes & Standards**
- **O&M, Diagnostics, Commissioning**



Element 5 Overview Integrated Commissioning & Diagnostics



- **Goals**
 - Commissioning of new commercial buildings as standard practice
 - Retro-commissioning and continuous monitoring of existing building systems widely practiced
- **Problem:** Buildings do not perform as designed or expected after handoff to building owners
- **Team**
 - Texas A&M
 - LBNL
 - PECI
 - MIT
 - UC Berkeley
 - University of Nebraska
 - Arup
 - Flack + Kurtz
 - Silicon Energy

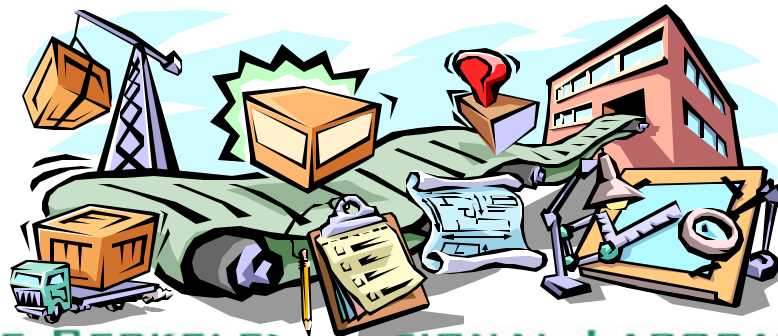


Problems and Opportunities

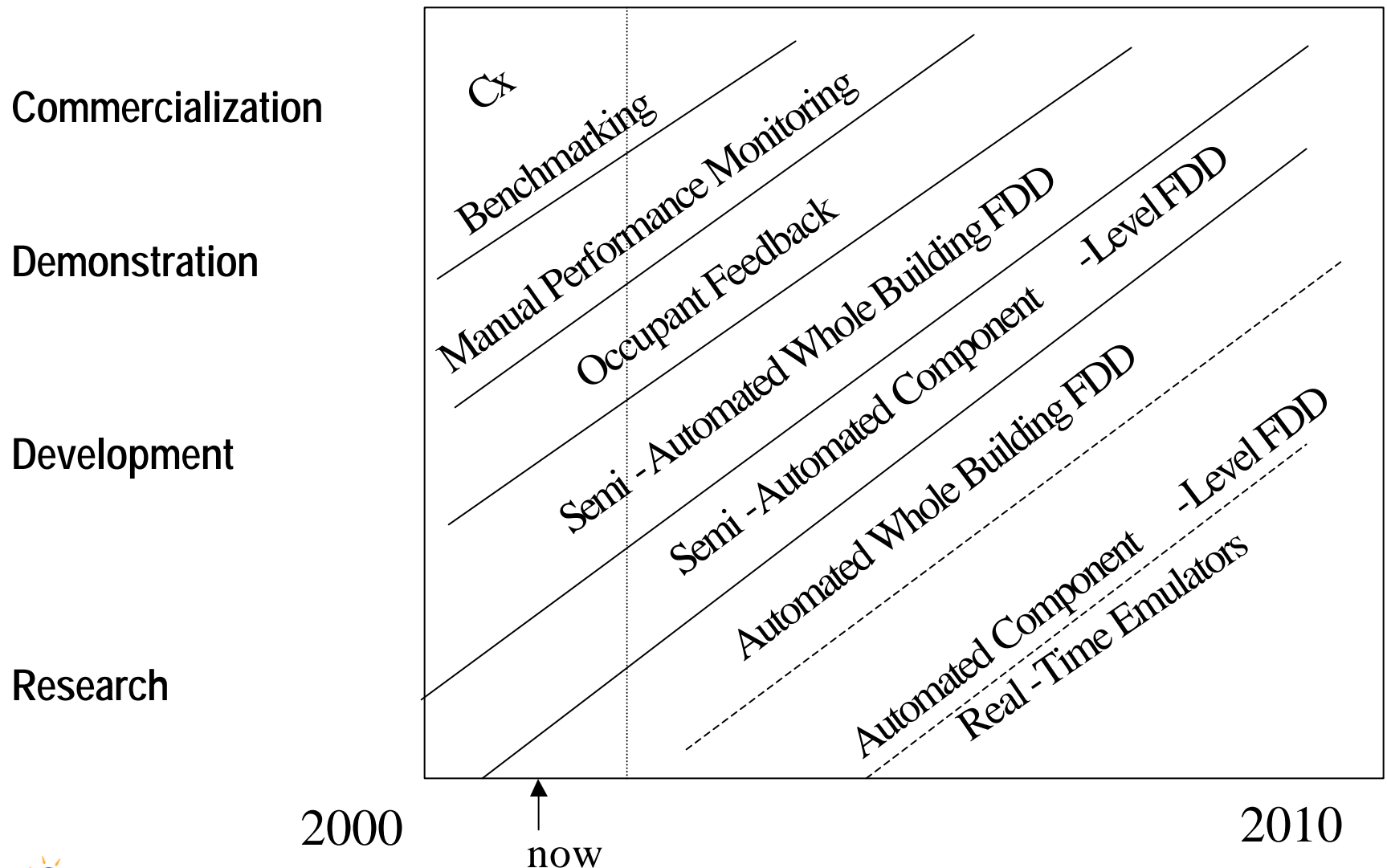


Design, construction and operations process is broken

- **Comfort and IAQ problems when new, increasing complexity**
- **Comfort and IAQ problems increase with age**
- **Efficiency decreases with age**
- Opportunities for early adopters
 - **Commission new buildings: eliminate most problems**
 - **Supplement operation with on-going and retro-commissioning**
 - Improved comfort
 - Energy cost cut by 10 – 20%



Layers to be Added to Simulation for Commissioning



Integrated Commissioning & Diagnostics Projects



New Buildings

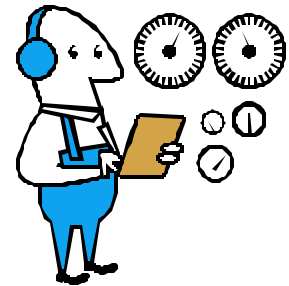
- Controls System Design and Functional Test Guide

Existing Buildings

- Fault Detection Procedures and Energy Information Systems
- **Guide to EMCS Use for Monitoring**
- **High-Information-Content Electrical Load Monitoring**
- **Occupant Feedback Methods**
- Commissioning Persistence

Advanced Methods

- **Simulation-Assisted Commissioning Procedures**
- **Tune-Up Procedures Based on Calibrated Simulations**
- Semi-Automated, Component-Level Diagnostics



Functional Testing Guide for Air Handling Systems



...From the Fundamentals to the Field

Extensive guide provides a practical understanding of the fundamentals

Includes field tips for functional testing

Coupled to PG&E's Commissioning Test Protocol Library

Fills a need for functional testing education

International dissemination

Functional Testing Guide for Air Handling Systems



Components included:

- Outdoor air intake
- Fan casing
- Economizer and mixed air
- Filtration
- Preheat
- Cooling
- Humidification
- Reheat
- Integrated operation & control
- Warm-up
- Fans and drives
- Distribution
- Terminal equipment
- Return, relief and exhaust
- Scrubbers
- Management and control of smoke and fire

Control System Design and Functional Test Guide



Background information describes test requirements and criteria

5.5.9.8. Relative calibration test

Energy and Other Benefits

Benefit	Comments
Energy Efficiency Related Benefits	1. Minimizes the potential for simultaneous heating and cooling due to the specific operating point of sensors with-in their accuracy window. The amount of energy wasted is proportional to the calibration error.

The energy transfers can be bad things if the goal is to not be transferring energy temperature rise across a heating coil that is supposed to be off probably means the control valve is leaking or that there is a problem with the control signal to the control valve. In either case, energy is being wasted at several points in the system specifically:

- Via unnecessary heating of the air at the coil.
- Via unnecessary heating plant energy to provide the necessary heat to the air stream.
- Via unnecessary cooling of the air stream to offset the unnecessary heating in order to maintain comfort.
- Via unnecessary cooling plant energy to provide the unnecessary cooling to the air stream.

These observations provide insight into the reasoning behind the opening statement of this section. In many instances, the relative accuracy of the sensors in a system is far more important than their absolute accuracy for ensuring efficient performance and detection of problems. The specification but not the absolute accuracy is what is needed. Consider a make up air handling system with a preheat coil and cooling coil with each coil in control. Let's further assume the coils are RTDs with an over-all accuracy of $\pm 1.5^\circ\text{F}$, a fairly common type of sensor and accuracy for this type of application. If we have simultaneous heating and cooling energy in a unsuccessful attempt to achieve a temperature that could have been achieved by simply bringing outdoor air to the current condition.

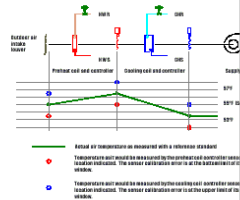


Figure 11: The impact of calibrated accuracy of identical sensors serving the same system and operating at different points their certified calibration accuracy window. This system uses 15°F cooling coil discharge temperature to satisfy the requirements of the system. It uses independent control loops for each heat transfer element, sensors serving the system meet the project's $\pm 1.5^\circ\text{F}$ accuracy requirement averaging type sensors. But, because the one serving the preheat coil is at the bottom limit of that range, it detects the outdoor air condition as lower than it actually is, even though this would not be necessary. The air reaches the cooling coil's controller which not only records the air is too hot but also adds heat by the preheat coil, but actually even cools the air it is operating at the upper limit of its accuracy window and thus detects it as being too hot. The result is simultaneous heating and cooling energy in a unsuccessful attempt to achieve a temperature that could have been achieved by simply bringing outdoor air to the current condition.

28

5.5. Economizer and Mixed Air Section

Background Information

Item	Comments
Purpose of Test	The purpose of the test is to ensure the relative accuracy of a group of sensors associated with a system or selected portion of a system where errors related to the calibration accuracy window of the sensors could cause energy to be wasted or operating data to be misinterpreted.
Instrumentation Required	The fundamental test can be performed with out any instrumentation other than the sensors that are being tested. However, a reference standard is helpful to establish the baseline for comparison when making adjustments. Minute by minute trending or data logging of the points under test will be useful to document the test results.
Test Conditions	The test is performed in a steady state condition.
Time Required to Test	The test takes approximately 15 to 30 minutes.
Acceptance Criteria	Acceptance criteria are as follows:
Potential Problems and Cautions	1. With the system in a steady state condition, all sensors read the same value relative to a baseline, with-in their accuracy tolerance prior to adjustment.

CTPL Reference

Non

Link to Functional Test RelCalFT

Air Handling Unit Temperature Sensor Relative Calibration Test

Instructions: For each system included on the checklist, verify the items indicated using **Yes** for acceptable, **No** for unacceptable, or **NA** for Not Applicable. For unacceptable items, identify what is required to correct the problem in the comments area provided. Use numbers to refer to comments. Identify the responsible contractor, if known, for any items requiring further action.

Equipment Required: Minute by minute trending of points to be tested (Optional); Lab grade thermometer (Optional, but highly desirable).

Acceptance Criteria: This test places the system in a steady state operating mode and then adjusts the return air temperature sensor, the mixed air temperature sensor, the warm-up coil discharge temperature sensor and the air handling unit discharge temperature sensor so that they read the same value when subjected to the same operating condition. Acceptance criteria are as follows:

1. With the system in a steady state condition, all sensors read the same value relative to a baseline, with-in their accuracy tolerance prior to adjustment.
2. With the system in a steady state condition, all sensors read the same value after adjustment.

The test will be performed at two different temperature levels in an effort to provide consistent readings from these sensors under all normally encountered operating conditions.

Date(s) of Test:

Time(s) of Test:

Test Technician

Item Number	Requirement	System 4-AHU-2
-------------	-------------	----------------

Prerequisites

1. Verify that all applicable prestart and start-up verification checks from the equipment manufacturer have been completed and that the system is fully functional.
2. Verify that the sensors that are to be tested are certified and installed per the accuracy requirements of the specifications.
3. Visually inspect the sensors that are to be tested to verify that they are installed in a manner that will allow them to measure the parameter intended and are free from influences due to mounting arrangement or configuration.
4. Verify that the loads served by the system can tolerate the 15 to 60 minute period of operation with out active discharge temperature control that is required to perform this test.

Preparation

1. Coordinate with the Owner and end-users served by the system for an appropriate test time. Note limits on deviations from set point that can be tolerated in the areas served and monitor these parameters during the test period.
 - General office area (monitor return temperature) $75 \pm 3^\circ\text{F}$
 - Computer room $72 \pm 3^\circ\text{F}$
2. Obtain copies of the specifications for accuracy for the sensors to be tested
3. Obtain copies of the factory calibration certificates for the sensors to be tested

Procedure

1. Document the current software calibration factors for the sensors to be tested in the

HPCBS

Air Handling Unit Temperature Sensor Relative Calibration Test

C:\Workpace\JLNL_Pier\ACUEE_Paper_Relative_Calibration_FT_Example.doc

Educational material explains and supports other information

Electronic links to sample procedures, test templates, and related information

Evaluation of Diagnostic & Energy Information Tools



Tool reviews and comparisons are included for these features:

Metering and connectivity

Data visualization

Demand response

Remote control

Financial analysis

International Conference for Enhanced Building Operations, 2003

Guide to Emerging Diagnostic Tools for Large Commercial HVAC Systems



- Compares tools to detection and diagnosis of problems
- Helps users understand key capabilities
- Provides tool developers with feedback by identifying important features and needs for future research

		Data Acquisition	Archive and Pre-process	Detection	Diagnosis
ENFORMA		○	◐	○	○
UCB Tools		○	○	○	○
UT (PG&E)		○	◐	◐	○
WBD	WBE	●	●	●	○
	OA/E	●	●	●	●
PACRAT		●	●	●	●
EEM Suite		●	●	◐	○

Automated



Partially automated



Manual



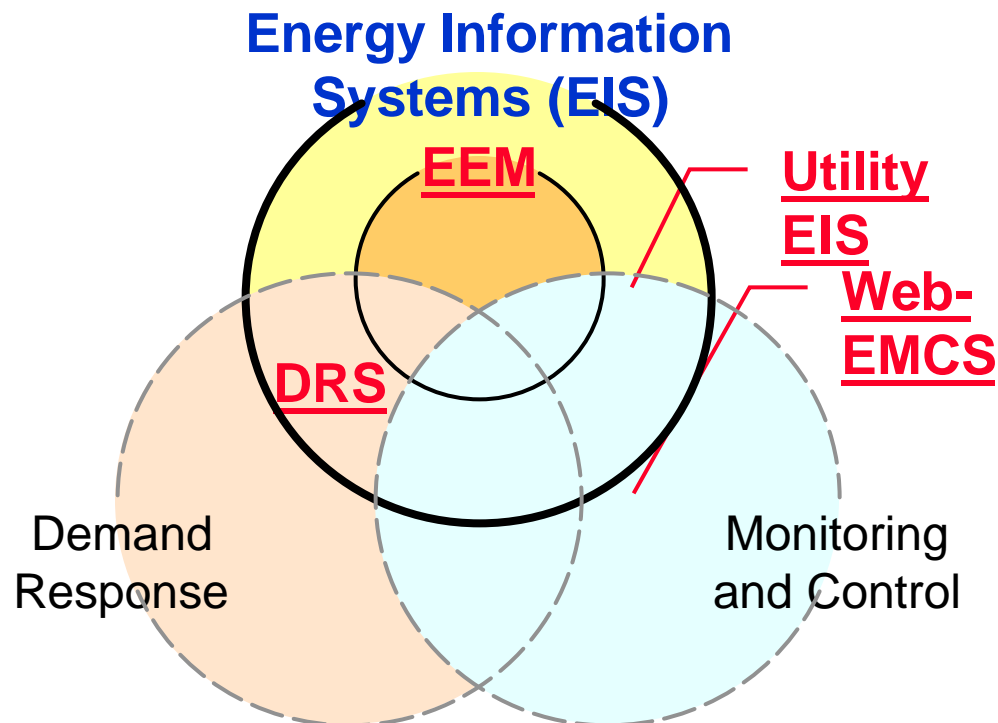
Web-Based Energy Information Systems



Market for EIS is growing nation wide, and faster in California.

Customers are often overwhelmed by EIS feature and application options

Objective of this report is to provide a technical overview of currently available EIS products



EIS Visualization & Analysis Features

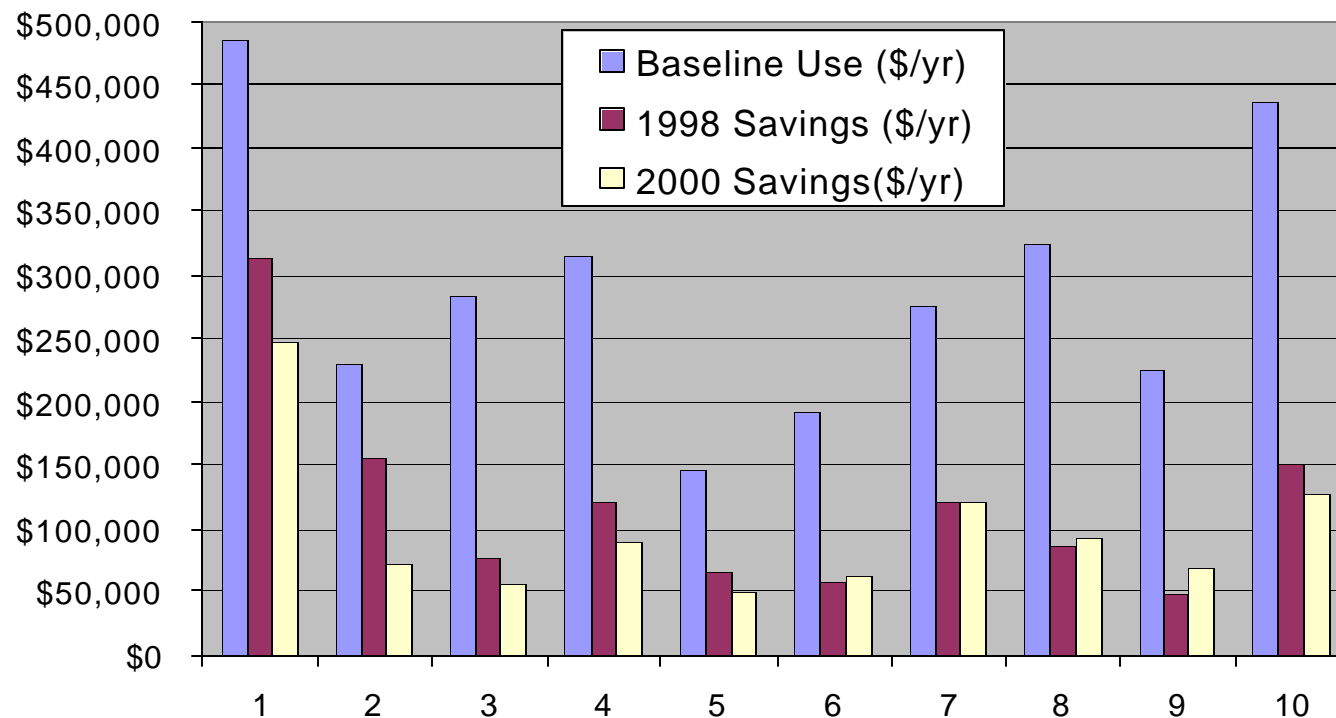


Software product	Forecasting	Per sqft	OAT plot	Aggregation	Calendar profile	Load duration	3D chart	X-Y scatter	Point overlay	Summary	Highs/lows	Average	Day overlay	Time series
AMICOS	✓			✓					✓	✓				✓
Enerlink.net		✓	✓	✓			✓	✓		✓	✓	✓		✓
Readmeter				✓		✓					✓			✓
EP Web					✓		✓		✓	✓	✓	✓		✓
Energy Profiler Online			✓	✓		✓			✓	✓	✓	✓	✓	✓
Load Profiler	✓		✓	✓					✓	✓				✓
UtilityVison	✓	✓		✓	✓				✓	✓	✓	✓	✓	✓
EEM Suite	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓	✓	✓
EnterpriseOne	✓	✓			✓			✓	✓	✓				✓
Intelligent Use of Energy	✓		✓	✓		✓			✓	✓			✓	✓
IMDS/Electric Eye	✓		✓				✓	✓	✓				✓	✓

Commissioning Persistence



- Are procedures implemented in commissioning defeated by operators?
- Persistence is a critical issue for building owners and public good programs



Strategies for Improving Commissioning Persistence



For building owners, managers, and operators:

Design Review

Building Documentation

Operator Training

Building Benchmarking (Cal-Arch)

Energy Use Tracking (EIS)

Trend Data Analysis (Diagnostics)

Recommissioning

Persistence of Savings from Commissioning

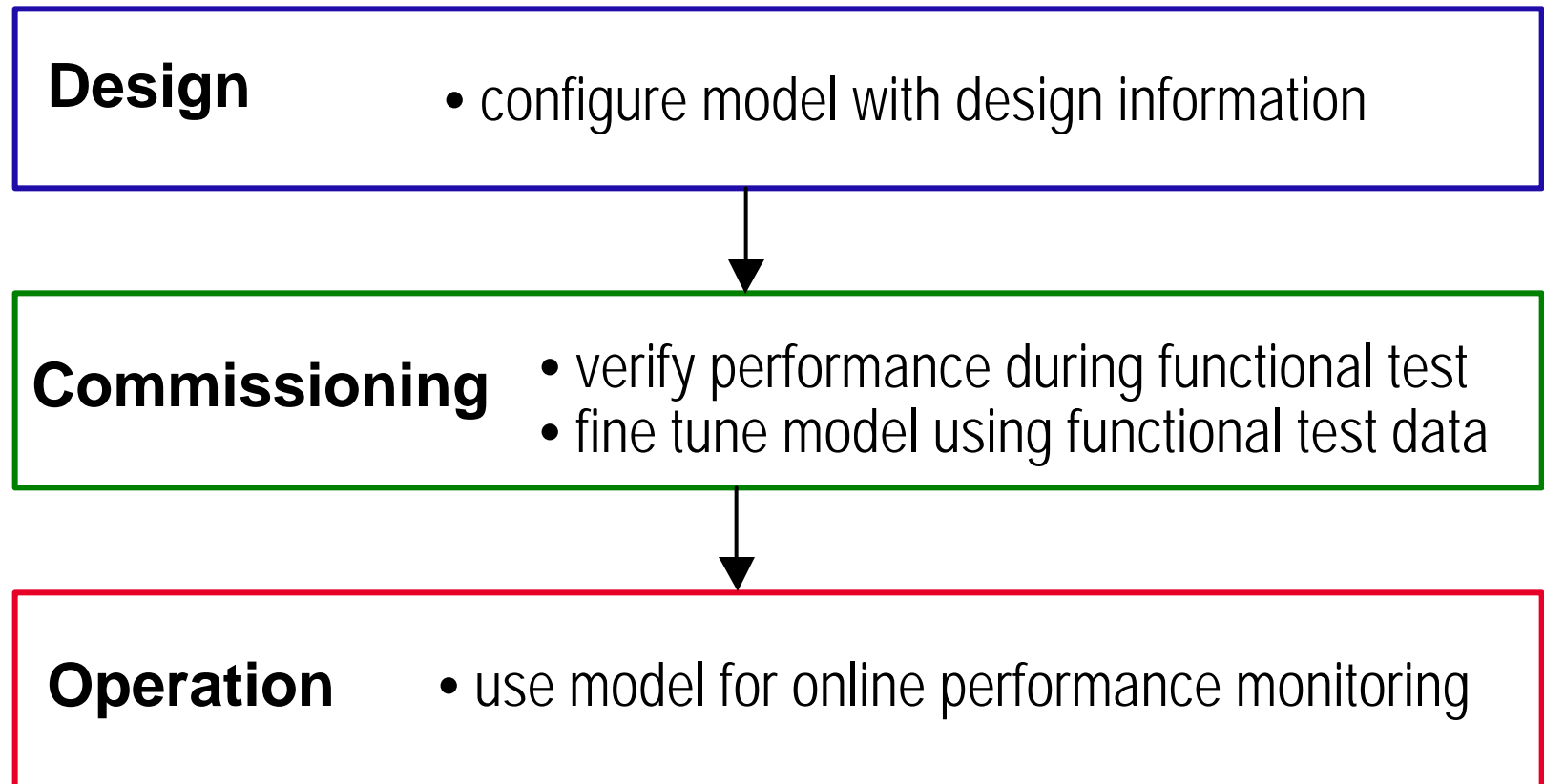


BUILDING (year commissioned)		DOCUMENTS			CENTRAL PLANT			AIR HANDLING AND DISTRIBUTION							PREFUNCTIONAL TESTS					OTHER				
		Commissioning report on site	Commissioning report used	Control sequences available	Chiller control	Cooling tower control	Boiler control	Hydronic control	Economizer control algorithm	Discharge air temperature reset	Simultaneous heating and cooling	VFD modulation	Dessicant cooling	Duct static pressure	Space temperature control	Terminal units	Piping and fitting problems	Valve modification	Wiring and instrumentation	Sensor placement or addition	Sensor error or failure	Scheduling	Skylight louver operation	Occupancy sensor
California	Lab and Office 1 (1996)	no	-	yes																				
	Office Building 1 (1996)	no	-	yes																				
	Office Building 2 (1996)	no	-	no																				
	Office Building 3 (1996)	yes	yes	no																				
	Office Buidling 4 (1994)	no	-																					
Pacific Northwest	Office Building 5 (1997)	no	-	yes																				
	Medical Facility 1 (1998)	yes	yes	yes																				
	Medical Facility 2 (1997)	yes	yes	yes																				
	Lab and Office 2 (1997)	no	-	yes																				
	Lab and Office 3 (2000)	no	-	no																				

Component-Level Diagnostics: Integrated Approach



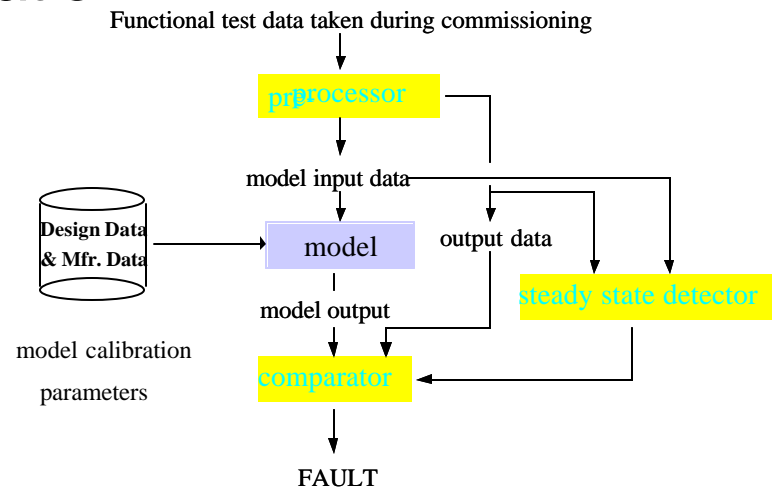
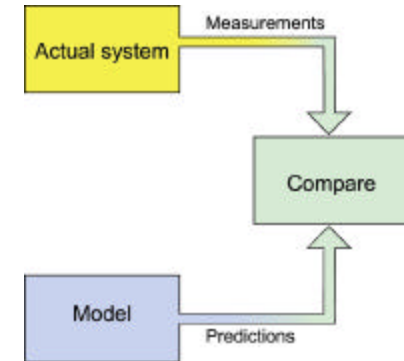
Use of models to represent correct operation:



Model-based Component-level Fault Detection



- Models of AHU and chiller in SPARK
- Methods for active tests & passive monitoring in C++
- Off-line testing using data from IEC and CA office buildings
- Interfaces for on-line operation under development

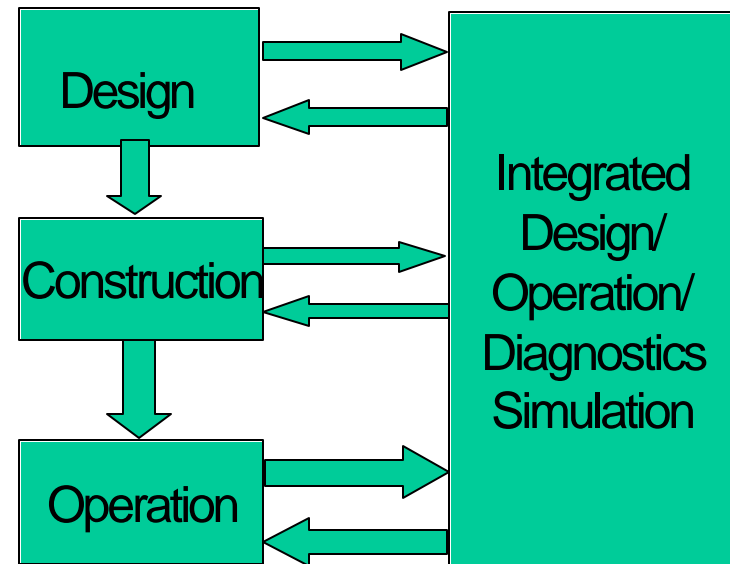


Commissioning and Diagnostics



Next Steps

- CEC
 - **Performance Monitoring Specifications**
 - **Demand Response testing and development**
- IEA Annex 40
 - **Automated FDD with international testing**
- ASERTI
 - **FT Guide dissemination and feedback**
 - **Educational material**
 - **Explore opportunities to automate tests**
- SMUD
 - **Study of 8 SMUD sites, interest from CCC**



Element 6: Energy and Indoor Environmental Quality (IEQ) in Relocatable Classrooms (RCs)



Goals

- Quantify and demonstrate opportunity for simultaneous energy savings and IEQ improvements
- Advance energy & IEQ technologies for RCs

Anticipated Long-Term Benefits

- Energy savings
- Improved health and learning

Team

- LBNL
- Davis Energy Group



RCs at an Elementary School

Technical Tasks



Energy and IEQ Field Studies

Construct, site, and monitor RCs with advanced energy and IEQ attributes.

- Advanced Hybrid HVAC technology
 - Indirect-Direct Evap. Cooling
 - Natural gas hydronic heating
- Assess Energy and IEQ benefits of advanced hybrid HVAC system
- Assess benefits of material testing and selection for low pollutant emissions



Energy simulations (DOE-2)

- Develop DOE-2 models for RCs
- Calibrate models using field data from Energy and IEQ study
- Predict statewide energy savings potential from advanced HVAC system

Key Findings

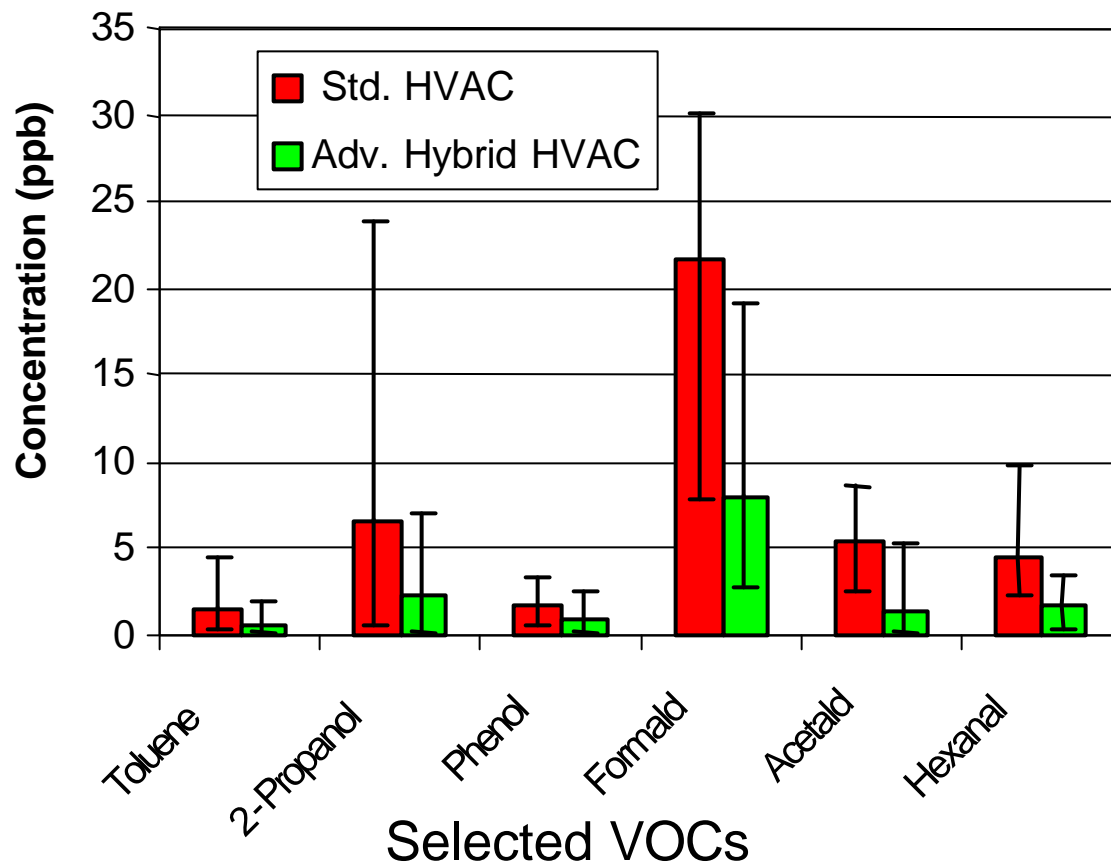


- **Advanced Hybrid HVAC**
 - Saved substantial energy
 - Provided thermal conditioning comparable to conventional HPAC systems
 - Significantly reduced indoor pollutants
- **Improved ventilation was more important than low-VOC building materials selection (may be manufacturer specific)**
- **It is practical to simultaneously reduce energy expenditure and improve IEQ**

Volatile Organic Compound Concentrations (VOCs) Reduction in Cooling Season



Avg. VOC Concentration & Range



Findings

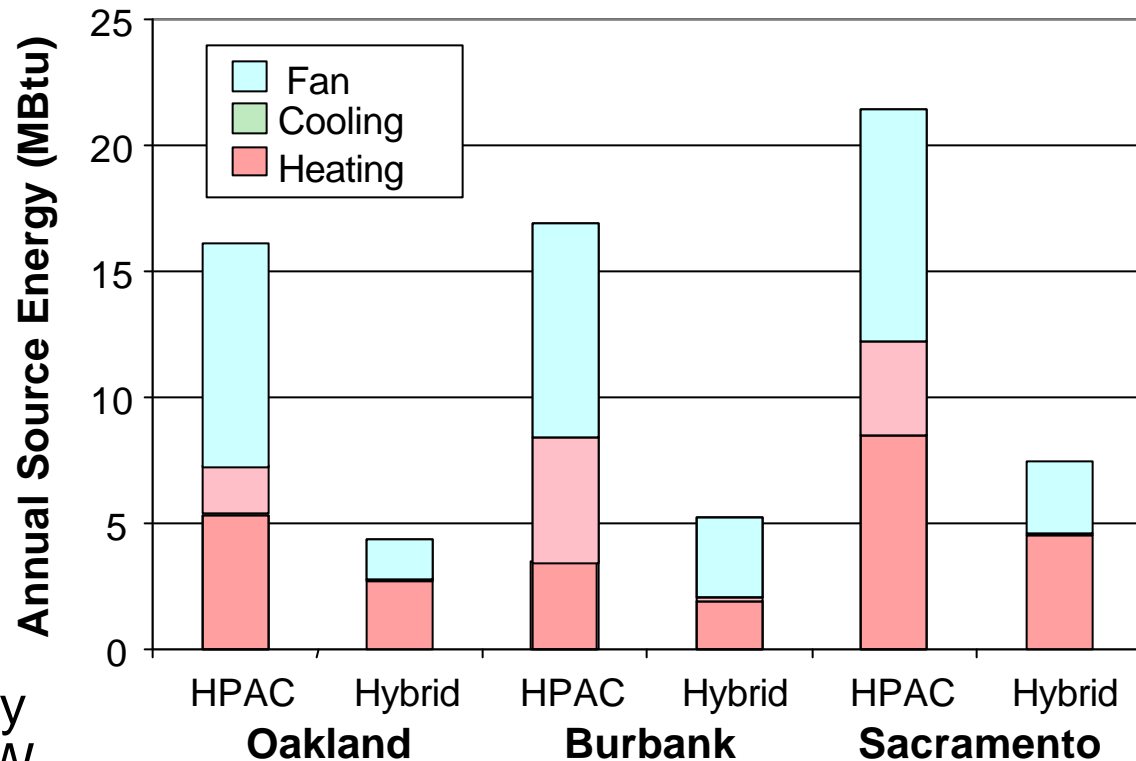
- Most concentrations were low in all RCs
- Formaldehyde occasionally exceeded OEHHA chronic non-cancer Reference Exposure Limit: 27 ppb for 8-hours
- Lower VOCs with advanced hybrid HVAC

Predicted Energy Comparison DOE-2 Energy Simulations Calibrated Using Field Data



Statewide yearly savings from use of advanced hybrid HVAC in 4,000 new RCs:

- save 6,000 MWh electricity
- reduce winter peak 24 MW
- reduce summer peak 13 MW
- increase natural gas 1020 Mbtu
- reduce school district operating costs by \$880,000



Recommendations*



- **Encourage and stimulate building design and operation for simultaneous energy savings and IEQ improvements**
 - Strengthen market pull through better quantification of benefits to occupants (e.g., improved health) and to employers and institutions (e.g., reduced absence, financial benefits)
 - Aggressively communicate results to stakeholders
 - Improve associated standards and guidelines
- **Continue development of low-energy, IEQ-superior HVAC**
 - Technologies must be considered practical by school districts
 - Different technologies for different climates
- **Improve ventilation system controls for schools**
 - Don't rely on teacher but keep controls simple

***Recommendations applicable for many types of buildings**

Questions?



More Information:

1. CDs with key deliverables
2. Project Brochures
3. Project Website:

<http://buildings.lbl.gov/hpcbs>